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TABLE OF CONTENTS

(See Index Following)

PAPERS

PAGE

SOME DETAILS OFTEN OVERLOOKED BY ENGINEERS, *A. Stucki*.......... 1

THE ZINC SMELTER OF TODAY, *F. E. Pierce*.......................... 20

ELECTRIC SERVICE PROBLEMS AND POSSIBILITIES, *P. Junkersfeld*........ 61

THE RELATION BETWEEN ENGINEERS AND CONTRACTORS, *J. W. Rollins*. 121

UNIVERSAL ELECTRICITY SUPPLY, *Samuel Insull*......................187

AFTER THE WAR, *Alba B. Johnson*................................195

THE NECESSITY FOR A NATIONAL DEPARTMENT OF PUBLIC WORKS, *Isham Randolph*..202

THE EXTENT TO WHICH SEWAGE CAN BE PURIFIED BY PRACTICABLE METHODS OF ARTIFICIAL TREATMENT NOW IN USE, *Harrison P. Eddy*.226

THE MATHEMATICAL THEORY OF THE ELASTIC ARCH, *Willis Whited*.....271

THE UTILIZATION OF BY-PRODUCTS FROM THE MANUFACTURE OF COKE, *C. G. Atwater*..345

THE MOBILIZATION OF MATERIAL AND INDUSTRIAL RESOURCES, *A. L. Humphrey*..381

SCIENTIFIC METHODS IN CONSTRUCTION, *Sanford E. Thompson* and *William O. Lichtner*.......................................433

WHAT CAN BEST BE DONE TO ADVANCE THE INTERESTS OF THE ENGINEERING PROFESSION IN THE UNITED STATES? *J. A. L. Waddell*...467

THE GLACIAL EPOCH, *Thomas P. Roberts*...........................565

SOME ASPECTS OF THE TESTING OF REFRACTORIES, *A. V. Bleininger*.....612

THE DESIGN OF SYMMETRICAL HINGELESS CONCRETE ARCHES, *Victor H. Cochrane*...647

NEW METHODS FOR MINING BITUMINOUS COAL AS PRACTICED BY THE H. C. FRICK COKE COMPANY.*Patrick Mullen*....................714

FACTORS AFFECTING COST OF STRUCTURAL STEEL SHOP WORK,*E. W. Pittman* 739

SOME ITEMS AFFECTING COST OF STRUCTURAL STEEL WORK, *George H. Danforth*...744

ENGINEERING PHASES OF SMOKE ABATEMENT, *Osborn Monnett*..........772

AN OUTLINE OF THE THEORY OF HEAT TRANSMISSION AND ABSORPTION IN APPLICATION TO ORDINARY ENGINEERING PROBLEMS, *John E. Bell*...797

AUTHORS.

Atwater, C. G. 345
Bell, John E. 797
Bleininger, A. V. 612
Cochrane, Victor H. 647
Danforth, George H. 744
Eddy, Harrison P. 226
Humphrey, A. L. 381
Insull, Samuel 187
Johnson, Alba B. 195
Junkersfeld, P. 61
Lichtner, William O. 433
Monnett, Osborn 772
Mullen, Patrick 714
Pierce, F. E. 20
Pittman, E. W. 739
Randolph, Isham 202
Roberts, Thomas P. 565
Rollins, J. W. 121
Stucki, A. 1
Thompson, Sanford E. 433
Waddell, J. A. L. 467
Whited, Willis 271

CONTRIBUTORS TO DISCUSSION AND CORRESPONDENCE

Affelder, L. J. 164
Affelder, W. L. 378, 724 *et seg*
Banks, J. E. 766
Baton, George S. 723
Bishop, F. L. 510
Blauvelt, W. H. 362
Blum, L. P. 18, 266
Bown, C. Elmer 112
Braude, H. 830
Breslove, Joseph 43
Brodie 454, 456, 460
Burns 730, 731, 734, 735
Burr, William H. 539
Cain, William 847
Campbell, J. W. 735
Case, George W. 259
Chase, C. E. 306, 308
Clay, F. W. H. 13, 114, 220
Consoer, A. W. 862
Danforth, George H. 793

Dexter, Gregory M....534
Didier, Paul....256
Diehl, A. N....634, 641, 644, 645
Dreyfus, E. D....101
Duff, Samuel....13, 169, 517, 520, 749
Egloff, Gustav....377
Emley, Warren E....223
Farnham, F. F....43, 44
Ferguson, John A....309, 512
Fettke, Charles R....606
Flanagan, V. J....862
Fleming, Thomas, Jr....257
Flint, W. P....376
Godfrey, Edward....519
Grove....735
Haggart, C. N....305
Handy, James O....55, 373, 376, 635
Hardesty, Shortridge....858
Harris, Henry....105
Hawley, W. C....155, 261
Henderson, J. W....794, 795
Henkele, E. W.... 15
Hice, R. R....596
Hiles, Elmer K....112
Hood, O. P....782
Hoopes, William....110
Hopkins, N. F....318
Howe, D. M.... 18
Ingalls, W. R.... 47
James, H. D.... 16
Jenks, J. S....109
Johnson, W. McA.... 56
Kelly, A. B....723
Kenney, R. M....732, 733
King, P. S....737
Knowles, Morris....215, 525
Kreisinger, Henry....783, 830
Layton, ...456
Leete, John H....523
Leighton, Henry....605
Lewis, Harry J....260, 609
Lincoln, P. M....107
Linton, Robert....54, 376, 729
McArthur, C. D....455, 456
McDonald, Hunter....527
McEwen, J. A....756

Macfarren, W. W. 728, 730, 734, 735, 736, 737
McKenzie, C. L. 178
McNaugher, D. W. 219
Marquard, F. F. 366
Martin, James S. 307, 308
Mason, J. R. 843
Mott, William E. 258, 537
Nesbitt, C. E. 635
Nichols, George W. 768
Older, Clifford 862
Orr, R. S. 100
Ortmann, A. E. 603
Paff, George A. 46
Patterson, Burd S. 217
Pendergrass, R. A. 759
Pierce, R. H. H. 640, 644
Porter, H. C. 372, 379
Porter, W. E. 791
Pritchard, Henry S. 167
Ramsburg, C. J. 369
Ray, H. C. 44
Rayman, 520
Rederer, B. S. 794
Rees, T. M. 793, 794
Reppert, Charles M. 263
Reuterdahl, Arvid 866
Rice, John M. 262
Roberts, Thomas P. 180
Rush, J. E. 265
Ryan, J. T. 729
Salt, T. V. 373
Scharff, Maurice R. 530
Schluederberg, C. G. 108
Scott, Charles F. 536
Shaw, Norman L. 791
Sincock, John 731
Smith, George K. 724, 727, 729
Snyder, G. W. 158
Speller, F. N. 516
Spofford, C. M. 341
Sprague, N. S. 254
Stratton, H. D. 790, 791
Stucki, A. 224, 457, 522
Swain, George F. 544
Talbot, K. H. 454
Taylor, E. J. 7

Thayer, H. R. 318, 765
Trinks, Willibald. 827
Uhl, E. J 768
Uhlenhaut, F. 111
Unger, J. S. 641
Waddell, J. A. L. 146, 857
Weldin, William Archie. 458, 733
Wenrich, C. N 828
Whitman, Paul S. 763
Wilkerson, T. J 767
Williams, Gardner S. 535
Wood, Robert, Jr. 736

INDEX

Affelder, L. J., Discussion on Engineers and contractors, 164.
Affelder, W. L., Discussion on By-products from coke, 378.
Affelder, W. L., Discussion on New methods for mining bituminous coal, 724, 726, 727, 728, 729, 730, 731, 732, 734, 735, 736, 737.
After the War, Alba B. Johnson, 195.
American Academy of Engineers, 492, 494, 501, 517, 522, 529, 539, 549, 557, 559, 560.
American Academy of Engineers, *See also* membership, under Engineering profession.
American Institute of Consulting Engineers, 493.
American Institute of Consulting Engineers, *See also* membership, under Engineering profession.
American Society of Civil Engineers; criticism of code of ethics, 543.
Arch, *See* Elastic arch design.
Arsenals, *See* munitions plants, under National defense.
Atmospheric nitrogen, *See* Nitric acid, under Coke by-products.
Atom, *See* Matter.
Atwater, C. G., *The Utilization of By-Products from the Manufacture of Coke*, 345.
Banks, J. E., Discussion on Structural steel costs, 766.
Baton, George S., Discussion on New methods for mining bituminous coal, 723.
Bell, John E. *An Outline of the Theory of Heat Transmission and Absorption in Application to Ordinary Engineering Problems*, 797.
Benzol, *See* Coke by-products.
Bishop, F. L., Discussion on Engineering profession, 510.
Bituminous coal mining, *See* Coal mining.
Blauvelt, W. H., Correspondence on By-products from coke, 362.

BLEININGER, A. V. *Some Aspects of the Testing of Refractories*, 612.
BLUM, L. P., Discussion on Details overlooked by engineers, 18.
BLUM, L. P., Discussion on Sewage disposal, 266.
Books, *See* Technical literature.
BOWN, C. ELMER, Discussion on Electric service, 112.
BRAUDE, H., Discussion on Theory of heat, 830.
BRESLOVE, JOSEPH, Discussion on Zinc smelter, 43.
Brick, *See* Refractories.
Bridge, *See* Elastic arch design.
Briquetting, *See* Zinc metallurgy.
BRODIE, —, Discussion on Scientific construction, 454, 456, 460.
BURNS, —, Discussion on New methods for mining bituminous coal, 730, 731, 734, 735.
BURR, WILLIAM H., Correspondence on Engineering profession, 539.
By-products, *See* Coke by-products.
CAIN, WILLIAM, Discussion on Symmetrical hingeless concrete arches, 847.
Calcium cyanamid, *See* Coke by-products.
CAMPBELL, W. W. Discussion on New methods for mining bituminous coal, 735.
CASE, GEORGE W., Discussion on Sewage disposal, 259.
Central station, *See* Electric service.
CHASE, C. E., Discussion on Elastic arch, 306, 308.
Chemical engineer, *See* engineer's services, under National defense.
City planning, *See* Engineering profession.
CLAY, F. W. H., Discussion on Details overlooked by engineers, 13.
CLAY, F. W. H., Discussion on Electric service, 114.
CLAY, F. W. H., Discussion on National Department of Public Works, 220.
Clay, *See* Refractories. Retorts.
Coal, *See* Smoke abatement.
Coal distillation, *See* Coke. Coke by-products.
Coal mining, 714.
  Cost, 738.
  Dangers, 725, 730, 737.
  Haulage, 715, 721, 726, 727.
  Labor, 715, 721, 727, 729, 736.
  Loading, 725, 727, 728, 734, 737.
  Rib-drawing by shortwall machines, 714, 729.
  Sprinkling, 725, 726.
  Timbering, 719, 735, 738.
  Tracklaying, 723, 726.
  Undercutting machines, 725.
  Ventilation, 715, 725.
  Wages, 721, 725, 736.
Coal-tar, *See* Coke by-products.
COCHRANE, VICTOR H., *The Design of Symmetrical Hingeless Concrete Arches*, 647.

Code of ethics, *See* Engineering ethics.
Coke, 345, 348, 363, 366, 370.
Coke by-products, 345.
  Ammonia, 349, 367, 380.
  Benzol, 355, 365, 368, 377.
  Calcium cyanamid, 352.
  Coal-tar, 358, 369.
  Cyanides, 357, 368, 376.
  Dyes, 374.
  Gas, 352, 363, 367.
  Nitric acid, 351.
  Oils, 360.
Coke oven gas, *See* gas, under Coke by-products.
Colloids, *See* Sewage disposal.
Concrete, *See* Scientific management.
Concrete arch, *See* Elastic arch design.
Concrete failures, 519, 551.
CONSOER, A. W., Discussion on Symmetrical hingeless concrete arches, 862.
Construction, *See* Scientific management.
Consulting engineer, 10.
Contractors; relations with engineers, 121.
Contracts between engineer and employer, 5.
  Uniform, 164.
Costs.
  Concrete, 447.
  Sewage disposal, 252, 264.
Crucibles; Alumina, 621.
  Carbon, 619.
  Magnesia, 620.
Cyanamid, *See* calcium cyanamid, under Coke by-products.
DANFORTH, GEORGE H., Discussion on Smoke abatement, 793.
DANFORTH, GEORGE H., *Some Items Affecting Cost of Structural Steel Work*, 744.
Design of Symmetrical Hingeless Concrete Arches, VICTOR H. COCHRANE, 647.
DEXTER, GREGORY M., Correspondence on Engineering profession, 531.
DIDIER, PAUL, Discussion on Sewage disposal, 256.
DIEHL, A. N., Discussion on Testing of refractories, 634, 641, 644, 645.
Disposal of sewage, *See* Sewage disposal.
Distillation of coal, *See* Coke; Coke by-products.
Donora Zinc plant, 20, 48.
Drafting, *See* drawings, under Structural steel costs.
Drainage, *See* land drainage, under Public works.
Dolomite, *See* Refractories.
DREYFUS, E. D., Discussion on Electric service, 101.
Dross, *See* residues, under Zinc metallurgy.
DUFF, SAMUEL E., Discussion on Details overlooked by engineers, 13.
DUFF, SAMUEL E., Discussion on Engineering profession, 517, 520.

Duff, Samuel E., Discussion on Engineers and contractors, 169.

Duff, Samuel E., Discussion on Structural steel costs, 749.

Dwight-Lloyd sintering process, 45.

Eddy, Harrison P., *The Extent to Which Sewage Can be Purified by Practicable Methods of Artificial Treatment now in Use*, 226.

Education, *See* Engineering education.

Egloff, Gustav, Discussion on By-products from coke, 377.

Elastic arch design, 271, 647, 846.
  Approximate methods advocated, 649, 650, 651, 652, 849, 857.
  Balet method, 284.
  Cain method, 284, 305, 307, 309.
  Characteristics of typical arches, 664, 667.
  Correction of maximum moments, 690.
  Ellipse of elasticity, 291, 299, 304.
  Geometrical form, 653, 654.
  Graphical methods, 279, 304, 309.
  Howe method, 284.
  Influence line diagrams, 648.
  Influence line formulas, 283, 869.
  Melan method, 306.
  Moment formulas, 686, 862.
  Mueller-Breslau method, 278, 306, 309, 318, 866.
  Ribs; variation in thickness, 660, 860, 870.
  Ritter method, 284.
  Stresses, 271, 279, 281, 283, 686, 856, 858, 859, 863.
  Symmetrical arch, 279, 284, 299, 654.
  Temperature effect, 848, 849, 857, 874.
  Thickness, 660, 662, 852, 854.
  Thrust formulas, 686, 865, 873.

Electric appliances, *See* domestic appliances, under Electric service.

Electric distribution, 188.

Electric furnace, *See* Zinc metallurgy.

Electric lighting,
  Cost, 78, 104.
  Lamp development, 90.
  Public relations, 87, 99, 112, 115, 116.

Electric lighting, *See also* Electric service.

Electric meter, *See* metering, under Electric service.

Electric service, 61, 187, 190.
  Classification of customers, 77, 78, 82, 99, 104.
  Cost, 70, 74, 75, 77, 104, 108, 109, 111, 113, 117.
  Density of customers, 70.
  Development, 61, 101, 106, 109, 194.
  Domestic appliances, 88.
  Economy, 70, 191.
  Electrification of steam railways., 83, 191.

  Metering, 75, 118.
  Power plant, 65, 189.
  Relations with the public, 87, 99, 112, 115, 116, 194.
  Vs. Electric energy, 67.
Electric service, *See also* Electric lighting.
Electric Service Problems and Possibilities, P. JUNKERSFELD, 61.
Electricity supply, *See* Electric service.
Electrification of steam railways, 83.
Electron, *See* Matter.
EMLEY, WARREN E., Discussion on National Department of Public Works, 223.
Employment of engineers, *See* employment, under Engineering profession.
Engineer, Consulting, *See* Consulting engineer.
Engineering contracts, *See* Contracts. Engineering ethics.
Engineering education, 12, 17, 468, 477, 528, 537, 542, 562, 565.
  Competitive problems, 516, 549.
  Courses of study, 479, 487, 488, 511, 518, 523.
  Courses of study; length, 479, 511, 518, 523, 525, 548, 551, 558.
  English language, 482, 523, 540.
  Enthusiasm, 480.
  Foreign languages, 483, 484, 529, 535, 539, 557.
  Improvement, 506, 546.
  Spanish language, 483, 512, 539.
  Systemization, 485, 489.
Engineering education, *See also* citizenship, under Engineering profession.
Engineering ethics, 1, 7, 11, 489, 543.
  Code for engineering profession in general, 498, 540, 561.
  Code of American Society of Civil Engineers; criticism, 543.
  "Extra work" in contracts, 140, 177.
  Lack of code, 472, 473.
  Relations between engineers and contractors, 121.
  Student instruction, 485.
Engineering laboratory, *See* research, under Engineering profession.
Engineering literature, *See* Technical literature.
Engineering Phases of Smoke Abatement, OSBORN MONNETT, 772.
Engineering profession, 467.
  Business features, 491, 515, 549.
  Citizenship, 491, 525, 536, 554.
  City planning, 509.
  Compensation of engineers, 498, 520, 547, 552.
  Co-operation, 534, 547.
  Deficiencies, 477, 542, 544, 560.
  Desirable improvements, 474, 477.
  Distinctions and honors, 486, 502, 547.
  Employment of engineers, 505, 530, 533.
  Epochs of engineer's career, 477, 486, 492, 513.
  Foreign work, 508.

  Government advisers, 497, 504, 511, 519.
  Lack of recognition, 470, 536, 547.
  Library, private, 485, 487.
  Licensing of engineers, 505, 557.
  Membership in societies, 488, 503, 517, 529, 532, 556.
  Municipal management, 509, 526.
  Public works, 515, 533.
  Publicity, 490, 556.
  Research, 498, 511, 548.
  Road building, 508.
  Status, 468, 514, 536, 539, 544.
  Technical writing, 489, 507.
Engineers in war, *See* engineer's services, under National defense.
Engineers' Society of Western Pennsylvania, 517, 551.
  Students' competition, 516, 549.
Ethics, *See* Engineering ethics.
European war, *See* War, European.
Extent to Which Sewage Can Be Purified by Practicable Methods of Artificial Treatment now in Use, HARRISON P. EDDY, 226.
Factors Affecting Costs of Structural Steel Shop Work, E. W. PITTMAN. 739.
FARNHAM, F. F., Discussion on Zinc smelter, 43.
FERGUSON, JOHN A., Discussion on Elastic arch design, 309.
FERGUSON, JOHN A., Discussion on Engineering profession, 512.
FETTKE, CHARLES R., Discussion on Glacial epoch, 606.
Fire brick, *See* Refractories.
FLANAGAN, V. J., Discussion on Symmetrical hingeless concrete arches, 862.
FLEMING, THOMAS, JR., Discussion on Sewage disposal, 257.
FLINT, W. P., Discussion on By-products from coke, 376.
Flotation; zinc metallurgy, 52.
Fluids; motion, 805, 806, 808, 809, 818.
Fraternities, Honorary, *See* distinctions, under Engineering profession.
Fuel; powdered, *See* Smoke abatement.
Fuel; Zinc metallurgy, 23, 37.
Fuel consumption in Electric service, 68.
Fuel economy through central station service, 191.
Furnace; zinc.
  Charging, 35, 36, 38.
  Hegeler, 29, 32, 36, 37, 40, 42, 47.
  Neureuther, 29, 30.
  Roasting, 32.
  Siemens, 29, 30, 37.
Furnace; zinc, *See also* electric furnace, under Zinc metallurgy.
Furnace temperatures, *See* Temperature measurement. temperatures, under Zinc metallurgy.
Gas, *See* Coke by-products.
Geology, *See* Glacial epoch.

Glacial Epoch, THOMAS P. ROBERTS, 565.
Glacial epoch, 565.
  Causes, 569, 573, 574, 578, 580, 592, 598, 607.
  Date, 571, 573, 597, 601, 605.
  Fauna, 566, 568, 577, 583, 589, 604, 607, 610.
  Flora, 570, 577, 582, 607, 611.
  Geology. Niagara, 601.
  Geology. Pennsylvania. 599, 606.
  Icebergs, 588, 593.
  Temperature, 580, 581, 585, 592, 603.
  Terminal moraines, 577.
GODFREY, EDWARD, Discussion on Engineering profession, 519.
Graphite, *See* carbon, under Refractories.
GROVE, —, Discussion on New Methods for mining bituminous coal, 735.
HAGGART, C. N., Discussion on Elastic arch design, 305.
HANDY, JAMES O., Discussion on By-products from coke, 373, 376.
HANDY, JAMES O., Discussion on Testing of refractories, 635.
HANDY, JAMES O., Discussion on Zinc smelter, 55.
HARDESTY, SHORTRIDGE, Discussion on Symmetrical hingeless concrete arches, 858.
HARRIS, HENRY, Discussion on Electric service, 105.
HAWLEY, W. C., Discussion on Engineers and contractors, 155.
HAWLEY, W. C., Discussion on Sewage disposal, 261.
Heat insulation, *See* Refractories.
Heat transmission, 797.
  Condensers, *See* pipes and tubes.
  Conduction, 797.
  Conductivity. 803, 804, 805, 833.
    Metals, 803.
  Convection, 797, 805, 832.
  Fluids, 809, 811, 817, 822.
  Furnace walls, 836.
  Gases, 802, 811, 812, 813, 814, 815, 827, 833, 839, 840, 841.
  Pipes and tubes, 807, 808, 810, 811, 813, 815, 818, 822, 823, 832, 839, 841.
  Pyrometric measurement, 802, 803.
  Radiation, 797, 799, 800, 801, 827, 828, 832, 844.
  Stefan's law, 800, 801, 829, 831, 836, 843.
  Surface combustion, 830.
  Wires, 826.
Heat transmission, *See also* Refractories. Temperature measurement.
Hegeler furnace, *See* Furnace.
HENDERSON, J. W., Discussion on Smoke abatement, 794, 795.
HENKELE, E. W., Discussion on Details overlooked by engineers, 15.
HICE, R. R., Discussion on Glacial epoch, 596.
HILES, ELMER K., Discussion on Electric service, 112.
Hingeless arch, *See* Elastic arch design.

History, *See* development, under Electric service.
HOOD, O. P., Discussion on Smoke abatement, 782.
HOOPES, WILLIAM, Discussion on Electric service, 110.
HOPKINS, N. F., Discussion on Elastic arch design, 319.
HOWE, D. M., Discussion on Details overlooked by engineers, 18.
HUMPHREY, A. L., *The Mobilization of Material and Industrial Resources*, 381.
Ice age, *See* Glacial epoch.
Incandescent lamp, *See* lamp development, under Electric lighting.
Industrial census, *See* census, under National defense.
Industry; effect of European War, 195.
INGALLS, W. R., Correspondence on Zinc smelter, 47.
Inspection; construction work, 163,
INSULL, SAMUEL, *Universal Electricity Supply*, 187.
Inventions; ownership, 4, 11, 15,
Investment, *See* expenses, under Electric service.
JAMES, H. D., Discussion on Details overlooked by engineers, 16.
JENKS, J. S., Discussion on Electric service, 109.
JOHNSON, ALBA B. *After the War*, 195.
JOHNSON, W. McA., Discussion on Zinc smelter, 56.
JUNKERSFELD, P., *Electric Service Problems and Possibilities*, 61.
Kaolinite, *See* Refractories.
KELLY, A. B., Discussion on New methods for mining bituminous coal, 723.
KENNEY, R. M., Discussion on New method for mining bituminous coal, 732, 733.
KING, P. S., Discussion on New methods for mining bituminous coal, 737.
KNOWLES, MORRIS, Correspondence on Engineering profession, 525.
KNOWLES, MORRIS, Discussion on National Department of Public works, 215.
KREISINGER, HENRY, Discussion on Smoke abatement, 783.
KREISINGER, HENRY, Discussion on Theory of heat, 830.
LABOR, *See* Coal mining. Zinc metallurgy.
Labor legislation, *See* National defense.
Laboratory, *See* research, under Engineering profession.
Land drainage, *See* Public works.
LAYTON, —, Discussion on Scientific construction, 456.
Lead poisoning, *See* Zinc metallurgy.
LEETE, JOHN H., Correspondence on Engineering profession, 523.
LEIGHTON, HENRY, Discussion on Glacial epoch, 605.
LEWIS, HARRY J., Discussion on Glacial epoch, 609.
LEWIS, HARRY J., Discussion on Sewage disposal, 260.
Libraries, *See* Technical literature.
Licensing of engineers, *See* Engineering profession.
LICHTNER, WILLIAM O., and THOMPSON S. E., *Scientific Methods in Construction*, 433.
LINCOLN, P. M., Discussion on Electric service, 107.
LINTON, ROBERT, Discussion on By-products from coke, 376.
LINTON, ROBERT, Discussion on New methods for mining bituminous coal, 729.

LINTON, ROBERT, Discussion on Zinc smelter, 54.
Literature, *See* Technical literature.
MCARTHUR, C. D., Discussion on Scientific construction, 455, 456.
MCDONALD, HUNTER, Correspondence on Engineering profession, 527.
MCEWEN, J. A., Discussion on Structural steel costs, 756.
MACFARREN, W. W., Discussion on New methods for mining bituminous coal, 728, 730, 734, 735, 736, 737.
Machine mining, *See* Coal mining.
MCKENZIE, C. L., Discussion on Engineers and contractors. 178.
MCNAUGHER, D. W., Discussion on National Department of Public Works, 219.
Magnesite, *See* magnesia, under Refractories.
Manufacturing; effect of European War, 200.
MARQUARD, F. F., Discussion on Coke by-products, 366.
MARTIN, JAMES S., Discussion on Elastic arch design, 307, 308.
MASON, J. R., Discussion on Theory of heat, 843.
Mathematical Theory of the Elastic Arch, WILLIS WHITED, 271.
Matter; structure, 797, 803, 827, 843.
Mechanical handling; zinc metallurgy, 35, 36.
Melting points, *See* fusing point, under Refractories.
Merchant marine, 198.
Metallurgy, *See* Zinc metallurgy.
Military preparedness, *See* National defense.
Military training, *See* universal training, under National defense.
Mine haulage, *See* Coal mining.
Mine ventilation, *See* Coal mining.
Mobilization of Material and Industrial Resources, A. L. HUMPHREY, 381.
Molecule, *See* Matter.
MONNETT, OSBORN, *Engineering Phases of Smoke Abatement*, 772.
Mortars, *See* Refractories.
MOTT, WILLIAM E., Correspondence on Engineering profession, 537.
MOTT, WILLIAM E., Discussion on Sewage disposal.
MULLEN, PATRICK, *New Methods for Mining Bituminous Coal as Practiced by the H. C. Frick Coke Company*, 714.
Municipal engineering, *See* municipal management, under Engineering profession.
Muffles, *See* Retorts.
National Academy of Engineers, *See* American Academy of Engineers.
National defense, 213, 381.
    Arsenals, *See* munitions plants.
    Census of resources, 389, 392, 475.
    Engineer's services, 381, 382, 387, 388, 432, 475.
    Labor legislation, 399.
    Mobilization, 388, 429.
    Munitions, 402, 405.
        Fuses, 422.

    Gages and tools for manufacturing, 415, 417, 419.
    Inspection, 419.
    Shrapnel, 389, 404, 415, 425.
    Specifications, 420, 422.
  Munitions plants, 385, 392, 393, 408.
    Assigned annual production, 392, 394.
    Conversion and organization of plant, 403, 410, 413, 417.
    Geographical location, 385, 387.
  National wealth per capita, 383.
  Naval Consulting Board, 387.
  Navy, 383.
  Transportation, *See* mobilization.
  Universal training, 213, 426.
  Wages, 400, 412.
    Of women workers, 402.
  Wisdom of preparedness, 382, 383.
  Women workers in shops, 401.
National Department of Public Works, *See* Public works.
Naval Consulting Board, 387.
Necessity for a National Department of Public Works, ISHAM RANDOLPH, 202.
NESBITT, C. E., Discussion on Testing of refractories, 635.
Neureuther furnace, *See* Furnace.
New Methods for Mining Bituminous Coal as Practiced by the H. C. Frick Coke Company, PATRICK MULLEN, 714.
NICHOLS, GEORGE W., Discussion on Structural steel costs, 768.
Nitric acid, *See* Coke by-products.
Ohio River; flow. 259.
OLDER, CLIFFORD, Discussion on Symmetrical hingeless concrete arches, 862.
Ores, *See* Sintering. Zinc.
ORR, R. S., Discussion on Electric service, 100.
ORTMANN, A. E., Discussion on Glacial epoch, 603.
Outline of the Theory of Heat Transmission and Absorption in Application to Ordinary Engineering Problems, JOHN E. BELL, 797.
PAFF, GEORGE A., Discussion on Zinc smelter, 46.
Patents, *See* Inventions.
PATTERSON, BURD S., Discussion on National Department of Public Works, 217.
PENDERGRASS, R. A., Discussion on Structural steel costs, 759.
PIERCE, F. E., *The Zinc Smelter of Today*, 20.
PIERCE, R. H. H., Discussion on Testing of refractories, 640, 644.
PITTMAN, E. W., *Factors Affecting Costs of Structural Steel Shop Work*, 739.
Pittsburgh.
  Geology, *See* Geology, Pennsylvania, under Glacial epoch.
  Sewage disposal, 259, 262, 263.
  Typhoid fever, 262.
Pleistocene epoch, *See* Glacial epoch.

Poisoning, *See* lead poisoning, under Zinc metallurgy.
PORTER, H. C., Discussion on By-products from coke, 372, 379.
PORTER, W. E., Discussion on Smoke abatement, 791.
Powdered coal, *See* Smoke abatement.
Preparedness, *See* National defense.
PRICHARD HENRY S., Discussion on Engineers and contractors, 167.
Public utilities, *See* Electric lighting. Electric service. Telephone.
Public works.
  Engineers as government advisers, 497, 504, 511.
  Land drainage by federal government, 209.
  Necessity for National Department, 202, 547, 563.
  River regulation by federal government, 216, 218.
  Water power development by federal government, 209.
Public works, *See also* Engineering profession.
Pyrometric cones, 622, 623, 627.
RAMSBURG, C. J., Correspondence on By-products from coke, 369.
RANDOLPH, ISHAM, *Necessity for a National Department of Public Works*, 202.
Rate making, *See* cost, under Electric service.
RAY, H. C., Discussion on Zinc smelter, 44.
RAYMAN, —, Discussion on Engineering profession, 520.
REDERER, B. S., Discussion on Smoke abatement, 794.
REES, T. M., Discussion on Smoke abatement, 793, 794.
Refractories, 612.
  Aluminous refractories, 612, 617, 618.
  Applications, 612.
  Bauxite, 612, 617, 618.
  Boron nitride, 621.
  Carbon refractories, 619.
  Chemical composition, 612, 613, 633.
  Chromite, 620.
  Classification, 612, 624.
  Coke bricks, 620.
  Constancy of volume, 623.
  Deformation, 625.
  Dolomite, 619, 635, 645.
  Fusing point, 612, 613, 621. *See also* temperature.
  Graphite, 619.
  Heat insulation, 617, 630.
  Iron oxide, 644.
  Kaolinite, 612.
  Magnesia refractories, 617, 618, 621, 644.
  Mortars and their effect, 634.
  Resistance to temperature variations, 629, 637.
  Shrinkage, 615, 617, 618, 623.
  Silica refractories, 613, 615, 616, 628.
  Slag penetration, 630, 637, 640.

- Spalling, 619, 637.
- Temperature; brickburning, 616.
  - Melting point of alumina, 617.
    - Bauxite, 617.
    - Chromite, 620.
    - Clays, 612, 613, 618.
    - Magnesite, 618.
- Testing, 612, 621, 641.
- Zirconia, 621.

Relation between Engineers and Contractors, J. W. ROLLINS, 121.
REPPERT, CHARLES M., Discussion on Sewage disposal, 263.
Residues, *See* Zinc metallurgy.
Resources, Natural, *See* census, under National defense.
Retorts; Zinc metallurgy, 25, 44, 47, 51, 58.
REUTERDAHL, ARVID, Discussion on Symmetrical hingeless concrete arches, 866.
Rib; concrete, *See* Elastic arch design.
Rib-drawing, *See* Coal mining.
RICE, JOHN M., Discussion on Sewage disposal, 262.
Roads, *See* road building, under Engineering profession.
Roasting furnace, *See* Furnace.
ROBERTS, THOMAS P., Discussion on Engineers and contractors, 180.
ROBERTS, THOMAS P., *The Glacial Epoch*, 565.
ROLLINS, J. W., *The Relation between Engineers and Contractors*, 121.
RUSH, J. E., Discussion on Sewage disposal, 265.
RYAN, J. T., Discussion on New methods for mining bituminous coal, 729.
Salary of engineers, 16.
SALT, T. V., Discussion on By-products from coke, 373.
SCHARFF, MAURICE R., Correspondence on Engineering profession, 530.
SCHLUEDERBERG, C. G., Discussion on Electric service, 108.
Scientific management.
- Concrete work, 446.
- Development, 436.
- Effect on workmen, 457, 462.
- In construction work.
  - Carpentry, 453.
  - Concrete costs, 445, 447.
  - Distribution of material, 440, 449.
  - Hauling, 454, 461.
  - Standardization of tools, 439.
  - Track elevation, 455.
  - Trenching, 438, 451.
  - Tunneling, 455.
- In manufacturing, 434.
- In mining, 459, 733.
- In municipal work, 435.

  Instruction, 442.
  Principles, 435, 464.
  Quality of work, 443.
  Wages, 445, 451.
Scientific Methods in Construction, SANFORD E. THOMPSON, and W. O. LICHTNER, 433.
SCOTT, CHARLES F., Correspondence on Engineering profession, 536.
Seger cones, 622, 623, 627.
Septic tank, *See* Sewage disposal.
Sewage.
  Composition, 227.
  Fertilizer value, 260, 267.
Sewage, *See also* Sewage disposal. Tannery waste. Trade wate. Typhoid fever.
Sewage disposal, 226.
  Aeration, 231, 237, 249.
  Biological problems, 265, 268.
  Broad irrigation, 231, 246.
  Chemical precipitation, 231, 237, 253.
  Classification of methods, 231, 252.
  Colloids, 228, 231, 238, 259, 266.
  Contact beds, 231, 239.
  Cost, 252, 264.
  Dilution, 229, 259, 270.
  Disinfection by chlorin, 258.
  Grit chambers, 231, 234, 253.
  Imhoff tank, 263.
  Incineration, *See* sludge.
  Pittsburgh, 259, 262, 263.
  Sand filter, 244.
  Screening, 232, 253.
  Sedimentation, 231, 233, 234, 237, 250, 253.
  Septic tank treatment, 231, 235.
  Sludge, 231, 247, 250, 253, 256, 266.
  Trickling filter, 231, 240.
Sewage disposal, *See also* Septic tank. Sewage. Tannery waste. Trade waste. Typhoid fever.
SHAW, NORMAN L., Discussion on Smoke abatement, 791.
Shortwall mining, *See* Coal mining.
Shrapnel, *See* munitions, under National defense.
Siemens furnace, *See* Furnace.
SINCOCK, JOHN, Discussion on New methods for mining bituminous coal, 731.
Sintering ores, 45.
SMITH, GEORGE K., New methods for mining bituminous coal, 724, 727, 729.
Smoke abatement, 772.
  Air jet, 791.

  Annealing ovens, 792.
  Boiler setting, 772, 775, 779, 794.
  Coals; comparison, 782, 785, 786, 790.
  Combustion space, 783, 784, 785, 786, 793.
  Draft for various rates of combustion, 772, 783, 786, 789.
  Dutch oven, 775.
  Grate surface, 772, 793, 794.
  Hand-fired furnaces, 775, 777, 787, 790.
  Heating plants, 777.
  History, 775, 778, 780.
  Mechanical stoker, 781, 786, 792, 795.
  Metallurgical furnaces, 792.
  Ordinances, 793.
  Powdered coal, 792.
  Smoke formation, 787.
  Steam jet, 777, 791.
  Temperature in stack, 775.
SNYDER, G. W., Discussion on Engineers and Contractors, 158.
Some Aspects of the Testing of Refractories, A. V. BLEININGER, 612.
Some Details Often Overlooked by Engineers, A. STUCKI, 1.
Some Items Affecting Cost of Structural Steel Work, GEORGE H. DANFORTH, 744.
Specifications.
  Benzol, 368.
  Bridge, 150.
  Munitions, 420, 422.
  Structural steel, 755, 758, 762, 771.
  Zinc, 22, 44.
Specifications, *See also* Engineering ethics.
SPELLER, F. N., Discussion on Engineering profession, 516.
Spelter, *See* Zinc.
SPAFFORD, C. M., Discussion on Elastic arch design, 341.
SPRAGUE, N. S., Discussion on Sewage disposal, 254.
Stefan's law, 800, 801, 829, 831, 836, 843.
STRATTON, H. D., Discussion on Smoke abatement, 790, 791.
Structural steel costs, 739, 744.
  Design, 739, 741, 744, 749, 756, 759, 760, 763, 766.
  Drawings, 740, 750, 758, 764, 766, 767, 768, 770.
  Drilling, 743.
  Erection, 754.
  Gussets, 747, 766.
  Mill order, 739.
  Punching, 740, 742, 743, 759.
  Reaming, 743.
  Riveting, 740, 742, 745, 746, 747, 762, 763, 764, 768.
  Shopwork, 744, 758, 760.
  Specifications, 755, 758, 762, 771.

Templets, 740.
Uniformity and standardization of design, 748, 750, 753.
STUCKI, A., Discussion on Engineering profession, 522.
STUCKI, A., Discussion on National Department of Public Works, 224.
STUCKI, A., Discussion on Scientific construction, 457.
STUCKI, A., *Some Details Often Overlooked by Engineers*, 1.
Surface combustion, 830.
SWAIN, GEORGE F., Correspondence on Engineering profession, 544.
Symmetrical hingeless arch, *See* Elastic arch design.
TALBOT, K. H., Discussion on Scientific construction, 454.
Tannery waste, 270.
Tannery waste, *See also* Sewage disposal. Trade waste.
Tar, *See* coal-tar, under Coke by-products.
TAYLOR, E. J., Discussion on New methods for mining bituminous coal, 727.
Technical literature, 498, 507, 512, 549.
Technical papers; suggested subjects, 499.
Technical writing, 489, 507.
Value of engineer's private library, 485, 487.
Technical societies, *See* American Academy of Engineers; American Institute of Consulting Engineers; American Society of Civil Engineers; Engineers' Society of Western Pennsylvania; membership, under Engineering profession; Naval Consulting Board.
Telephone service, 91.
Temperature, *See* Elastic arch design. Glacial epoch. Heat transmission. Smoke abatement, Temperature measurement. Zinc metallurgy.
Temperature measurement.
Pyrometer, 802, 803.
Pyrometric cones, 622, 623, 627.
Testing refractories, *See* Refractories.
THAYER, H. R., Discussion on Elastic arch design, 318.
THAYER, H. R., Discussion on Structural steel costs, 765.
THOMPSON, SANFORD E., and LICHTNER, W. O., *Scientific Methods in Construction*, 433.
Timbering, *See* Coal mining.
Trade waste, 252, 270.
Trade waste, *See also* Sewage disposal. Tannery waste.
Transportation, *See* mobilization, under National defense.
TRINKS, WILLIBALD, Discussion on Theory of heat, 827.
Typhoid fever, 262, 268.
UHL, E. F., Discussion on Structural steel costs, 768.
UHLENHAUT, F., Discussion on Electric service, 111.
UNGER, J. S., Discussion on Testing of refractories, 641.
Universal Electricity Supply, SAMUEL INSULL, 187.
Universal military training, *See* National defense.
Utilization of By-Products from the Manufacture of Coke, C. G. ATWATER, 345.
Viscosity, *See* Fluids.

WADDELL, J. A. L., Correspondence on Engineers and contractors, 146.
WADDELL, J. A. L., Discussion on Symmetrical hingeless concrete arches, 857.
WADDELL, J. A. L., *What Can Best be Done to Advance the Interests of the Engineering Profession in the United States?* 467.
Wages, *See* Coal mining. National defense. Salary.
War, European; effect on America, 195.
War, European, *See also* National defense.
Water power, *See* Public works.
WELDIN, WILLIAM ARCHIE, Discussion on New methods for mining bituminous coal, 733.
WELDIN, WILLIAM ARCHIE, Discussion on Scientific construction, 458.
WENRICH, C. N., Discussion on Theory of heat, 828.
What Can Best be Done to Advance the Interests of the Engineering Profession in the United States? J. A. L. WADDELL, 467.
WHITED, WILLIS, *The Mathematical Theory of the Elastic Arch*, 271.
WHITMAN, PAUL S., Discussion on Structural steel costs, 763.
WILKERSON, T. J., Discussion on Structural steel costs, 767.
WILLIAMS, GARDNER S., Correspondence on Engineering profession, 535.
WOOD, ROBERT, JR., Discussion on New methods for mining bituminous coal, 736.
Zinc.
    Ores, 30, 52, 54.
    Properties, 22.
    Specifications, 22, 44.
Zinc dust, 23.
Zinc metallurgy, 20.
    Briquetting, 59.
    Cost, 49,58.
    Donora, Pa., 20, 48.
    Electric furnace, 43, 57.
    Flotation, 52, 59.
    Fuel, 37.
    Iron in furnace charge, 44.
    Labor, 38.
    Langeloth, Pa., 20, 48.
    Lead poisoning, 41.
    Mixing of charge, 34, 43.
    Residues, 40, 41, 43, 45, 46, 54, 55, 60.
    Temperatures, 51, 53.
Zinc metallurgy, *See also* Flotation. Fuel. Furnace. Mechanical handling. Retorts. Sintering. Zinc.
Zinc Smelter of Today, F. E. PIERCE, 20.

SOME DETAILS OFTEN OVERLOOKED BY ENGINEERS

By A. Stucki*

At one of the meetings of the International Engineering Congress in San Francisco, Dr. Brashear reminded us again that God made the world and that the engineer made it fit to live in.

It is the engineer and engineering skill which make it possible to cross the seas; to span the rivers and to pierce the mountains. He penetrates the wilderness; lays out the tracks and overcomes the almost insurmountable obstructions that nature has laid in his path. Habitation follows and the treasures of our mother earth, be it above the surface or below, can now be utilized.

It is the engineer again who has made it possible to link the nations by a mailing system, by telegraph and telephone and by means of transportation, so that an exchange of learning, foodstuffs and raw material can take place.

The engineer is at the bottom of all industrial developments. It is he who works out the various problems, be it the piercing of the eye in a needle, or the construction of a million pound capacity forging press, and for this reason he is primarily responsible for our industrial success and the enormous wealth produced by manufacturing.

Does he get his proper share of what he produces? I say emphatically "No," and I feel sure that all of you agree with me. Engineering is a profession and whatever is being worked out, is only paid for once, while the installation, after having been made, will repeatedly bring in returns. Let us for instance take a wire nail machine: Its design entitles the engineer to one pay only, while the machine perhaps is duplicated by the thousands, each one bringing in returns by every stroke, from morning until night, from month to month, year in and year out.

This is a natural, well understood condition, which cannot be changed, but the apparent unfairness has received the consideration of many broad minded people and the patent laws are such as to take care of the engineer as far as possible, provided he avails himself of this protection at the proper time and in the proper way.

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In regard to the efficiency of our engineers, we can point with pride to what has been accomplished, and our great and glorious country in itself is a living proof of the high standard of the profession. The respective schools are making great strides to enable their students to acquire a thorough professional basis for their future work and the engineers' societies are doing all they can to assist their members in their daily task, to bring about new developments and to unite the individual efforts into general and more effective movements, and all that need be said is "keep on going."

The author intends to speak more about matters partly outside the technical field which are often overlooked and which are just as important to the individual success, as engineering skill and technical training. But the field is so large and the conditions in each branch so different that it was deemed advisable to subdivide the question and to consider the conditions as they are met by:

1. The Engineer
2. The Engineer in Charge.
3. The Consulting Engineer.

THE ENGINEER

We understand the Engineer here to mean the man who does the actual work either at the board, the field or otherwise.

This man now usually comes from a technical school and brings with him a diploma, saying that he graduated in an engineering course, and we very often translate this to mean that he is an engineer. This is a great mistake and it often handicaps a graduate for years until he finds out that a diploma simply certifies the passage through a preliminary training, sufficiently thorough to start real work and to begin a new and unlimited study.

I also know of cases where young men, who, after having gone through a couple of courses of night and correspondence schools, have assumed such a superior air that the effect ultimately was decidedly damaging.

For this reason we admire all the more the young man and especially the college graduate who takes hold of his work with a whole-soul spirit, no matter how insignificant or how tedious the job may be. We like to see him work at it with almost visible contentment and to see him solve the question in a most practicable way. We notice him as he asks friends and colleagues for information, consults his note book and the engineering hand books. Not only that—he goes right to the shops to learn what really is required and he does not rest until, to his own satisfaction, he has worked out the various possible methods in which the task can be accomplished. Then he reports to his superior, showing what he has done and expecting a decision along the lines he should proceed.

Everybody is willing and eager to help along a young man with this spirit and if any changes or promotions are contemplated he is not overlooked.

Often the salary seems small to us, especially if by chance we know what our superior gets. Such deliberations often make us unfit for congenial and effective work. Here we simply should consider that the salary we get is only a part of our pay. The experience we get is worth a great deal more and is an asset which accumulates much faster than the monetary end; in fact, this period should be considered an extension of our school work.

After obtaining a certain degree of efficiency, a man often feels that he is entitled to a better grade of work, getting disgruntled, if an inferior job is given him. Each man is justified to expect improvements along this line, in fact, this is almost necessary to keep up interest. However, no matter how unimportant an occasional case may be, it should be worked up with the proper spirit, else working is a curse.

In this connection, I vividly remember a case when a designer was asked to measure up an old brick building formerly used as an ice house. This work did not require much ingenuity and in order not to let it get uninteresting the man resolved to see how nice a drawing he could make of it. The result was that his superior and his colleagues all complimented him and it formed an inspiration for a great many others. In fact, this man told me that he had more satisfaction from this very case than from a good many engineering problems.

As said above, a man must have ambition, but only within certain bounds. We often think in working out details that we have made a great invention which should be covered by a patent, while in reality it is nothing else but the mechanical execution of the underlying principle given us by our superior. Such a spirit is unfortunate. It undermines the confidence in us and causes the department head to question our sincerity. We, on the other hand, feel hurt because we did not get the opportunity to enroll as patentee. We get discouraged and soured and the first step downward has been taken.

Often a man sticks to his post for years, does splendid work, is trusted and esteemed, but for some business reasons, his salary may not be increased as fast as he expected. In such a case we often get disgruntled, careless and unhappy and do not realize that we hurt no one but ourselves. In fact, by so doing, we will be given less and less important work, we will be more and more ignored, and finally the great "injustice" becames unbearable and we quit the job disgusted.

A much wiser plan is to take the superior into your confidence and let him know your wishes, but let us remember that there are always two sides to a question. The good will may be there, but the business end may not allow it. In such a case fair and most careful judgment should be used and whatever we decide to do, we dare not cease to work with interest and in the most congenial way, or else we lose the battle.

As an engineer becomes experienced in a certain line, his aspirations to improve and to invent are justified and he should be strongly encouraged in such work, and any new design, new method or improvement should be ordered patented. In all such cases an initial understanding should exist that such inventions are turned over to the firm, who will in turn pay all expenses, also a stipulated sum to the inventor, and every man in entering the service should sign such an agreement.

This naturally would not affect inventions made outside of the employer's business hours and outside his line of work.

Agreements of this sort avoid misunderstandings and will prevent the men from getting disappointed, discontented and disheartened. The firm itself gains also. It will get far ahead of its competitors in methods and equipment and it will not have to fear that such improvements can be copied or acquired by other ambitious concerns.

A fair form of such a contract, one that has been used for many years by a large manufacturing concern of a railway specialty, has been patterned after and is given below:

MEMORANDUM OF AGREEMENT

WHEREAS, John Smith, of Greensburg, Pa., is in the employ of the Mould Glass Company as draftsman; and

WHEREAS, On account of the position so held by him, he has free access to the Mechanical Department of said company, and special opportunity to become familiar with the art of making glass and moulding it in special forms, and may from time to time make improvements in the designs, methods and in the construction of the moulds or other machinery pertaining to this industry;

NOW, THEREFORE, The said John Smith, in consideration of such employment by said company and the further consideration hereinafter named, hereby covenants and agrees, that in case he shall during his employment by said company make and invent any improvement in the manufacture of glass, or in the equipment or machinery relating thereto, he shall within a reasonable time of making such invention disclose the same to the manager of the department of said company in which he is then employed, or to the general officers of the company having charge of the manufacturing department, and if desired by such general officers, shall, at the expense of said company, duly make application for Letters Patent of the United States for such invention or improvements, and shall assign the entire interest in such invention and application to the said Mould Glass Company, its successors and assigns.

IN CONSIDERATION WHEREOF the said Mould Glass Company hereby covenants and agrees to pay unto the said John Smith for every such invention so made and submitted to it, and for which application for patent shall be made at its request as above provided, the sum of............................ dollars, and said company further agrees, that in case the invention for which such application is made as above provided shall be considered by the general officers of the company having charge of the Manufacturing Department to be of sufficient value to justify payment of a larger consideration for the same, then said Mould Glass Company shall pay to said John Smith such sum in cash as shall be deemed proper by such general officers.

In Testimony Whereof the said John Smith has hereunto set his hand and seal, and the said Mould Glass Company has hereunto affixed its seal, attested by one of the officers of said company, this 15th day of January, 1916.

John Smith, (Seal)

Witness: Harry Jones.

Mould Glass Co.,
By Geo. Brown, Mgr.

Such a contract protects the Company completely in its business, it stimulates the proper efforts of the men, and at the same time leaves them free to work in any other line if they desire to do so.

In cases where the employer only manufactures for his own use, such as for instance railroads, the employee as a rule turns over only working licenses and keeps the balance of the patent rights with the privilege to sell it to whom he pleases. This gives the engineer important chances, without, however, hampering the company by whom he is employed.

The stumbling block, however, in such cases is the fact that it is hard to sell a patent or to work it on a royalty basis with success unless we have abundant time, are well known and have influence, and for this reason I am safe to say that more than one half of the patents taken out do harm to the inventor instead of good.

Unfair contracts occasionally are also offered and the author came across a certain case in which one article for instance read as follows:

> "The second party covenants and agrees for himself, his legal representatives and assigns, that all mechanical and other inventions which he may make during said period and any and all letters patent of the United States, or of any other country, which may be issued therefor, or any applications for letter patent which may be made for any such inventions, shall be the sole and exclusive property of the party of the first part, and that he will, either before or after the issue of any such letters patent, make good and valid assignments thereof unto the first party, his legal representatives and assigns."

Such stipulations are unreasonable and illegal, as they would make slaves of men. Here engineering skill was purchased like commodities, like colored flesh dealt in decades ago.

Closely connected with this subject are the cases in which an engineer is simply hired to work up patents. I know of a promotor, who constantly keeps three or four men working for this very purpose and a great many patents are constantly assigned and added to his holdings every year. In one of the recent issues of the Official Gazette, a weekly issue, not less than nine such patents came to my attention. Unfortunately, a good many of such patents are merely of a protective nature, so as to keep someone else from manufacturing something on a similar line, and from a purely business standpoint nothing can be said against such a course. None the less, it often hampers industrial developments, which is just the reverse of what our patent laws were enacted for, and looking at it from this point of view, it certainly appears that arrangements such as they have in Canada, for instance, would serve this general purpose better. There the patent, in order to be valid, must be worked within a certain period unless it is taken out under a compulsory license clause, which gives any one a right to manufacture against a license, if the owner does not wish to manufacture the article himself.

To come back to our original case, nobody can deny a business man or a promotor his right to employ an engineer to simply work up patents, as explained, but inasmuch as future advancements are usually out of the question, it is well for the employee to see that he gets proper compensation right from the beginning.

The American Society of Civil Engineers, not long ago, investigated the conditions and the compensations of its members, and no doubt was very much encouraged in this work, at any rate the inquiries were later on extended to the members of the other National Societies, and let us hope that such investigations will lead us to a better understanding and to additional protection for the engineer.

ENGINEER IN CHARGE

The engineer in charge has naturally broader duties to perform. He has to guard the interests of his firm, those of his subordinates, his own and those of the engineering profession at large.

An excellent guide in many respects will be found in the Code of Ethics, recommended by the American Society of Mechanical Engineers. It sets forth

"The Engineer's relations to the client or employer,"

"Ownership of engineering records and of data,"

"The Engineer's relations to the Engineering Fraternity."

Under the latter heading there is a paragraph as follows:

"The attitude of superiors towards subordinates should be that of helpfulness and encouragement. The attitude of subordinates to superiors should be one of loyalty and diligent support. The treatment of each by the other should be open and frank."

Very little need be said aside from this. Are we always frank, especially towards our subordinates? Do we realize that absolute straightforward criticism helps the man to overcome his shortcomings and to make a useful engineer of him? We hear so often the expression: "He was no good, I had to let him go." Was this man warned beforehand? Was he frankly dealt with, or was he simply gradually reduced by giving him work of less and less importance?

Another way to create interest and ambition in the men is to treat them all impartially, as nothing undermines the good results in any office faster than the feeling that partiality prevails. The only remedy in such a case is to remove the man, i. e., the man in charge.

To guard the interests of the employer is a higher duty than to guard our own position. Every man in charge should have his right hand man, and he in turn somebody else, and every one in line should be sufficiently equipped to take the next man's place. This way no death or any other changes can undermine the proper working of an office and such an attitude will be appreciated by the firm and be admired by every one. Besides all that, the young man down the line has an assurance to be some day the head of this procession.

Are we always determined to get an increase in salary of subordinates, if such an increase is merited and possible? The plea is made so often that the firm cannot afford it. None the less, that very money often goes to higher men, whose salary is already high, less warranted and less productive. Should there be any wonder that the service of the engineer is often underestimated, because it is so cheap?

The case is somewhat different with the Engineer in Charge. He must consider three items in his compensation—the salary, the position and the standing of his firm.

The salary is necessary to take care of the present. A position acknowledges in other ways that we have done our duty in the past and a high standing of a firm is the best assurance for our future.

I know one case where disregard of this last item worked hardship to the man at fault. He was the chief executive in the engineer's department of a large combine, who let tremendous contracts. He was a conscientious and painstaking engineer and was resolved to have the work inspected in this spirit. This did not suit the other side, i. e., the contractor, and in order to get rid of such unreasonable inspection, as it appeared to him to be, he offered this engineer a high position in his own concern with a salary much higher than he got before. Our friend accepted and thus had the salary and also the position, but he did not have the third important item, and in consequence was looking for a job a few months later.

Gentlemen, are we not taking similar chances every day? How often do we enter new positions without considering the standing of the firm sufficiently, without the signing of a contract or a written understanding?

On general principles I am not in favor of a purely time contract, as it might have an influence on the efforts, more or less hurting the man as engineer. It would put him somewhat on the same footing of a mechanic in a labor union. "He would get good pay, whether he is a good man or not."

However, there are cases where the conditions justify a man to demand just such a contract. For instance, if he is eminent in one certain line, or he is wanted by some rival companies, or is compelled to move with family far from his previous abode, or is in the possession of patents which have a bearing on his future work. In all such cases a contract should precede a change in occupation.

A very interesting case on the same subject came to light not long ago, when an engineer of one of our large manufacturing concerns was induced to enter work with a much smaller one, and after the old ties were severed, a contract was presented to the engineer which was unfair and far from verbal understandings, but he was not the chooser any longer, hence, was compelled to sign.

Such cases as those mentioned, no matter how exceptional they are, should be eliminated, especially since it can be done by simply using business methods so well established in the other lines. This way the public will respect the whole profession that much more.

The American Association of Engineers, recently established, has similar points in view. It is an independent national society and tries to bring the engineers and their profession more and more before the public, be it by the press, lectures or other means. Just what will be accomplished by a movement of this sort cannot be stated at this time, but let us hope that it will prove to be a step in the right direction.

CONSULTING ENGINEER

The Consulting Engineer undoubtedly is the most important factor in the development of a country. He, as a rule, is compensated by a salary, and if his line of work is such as to make production on a large scale possible, he also gets a small commission, bonus, stock or royalty, but all these compensations as a rule are very small compared with what he produces.

We must, of course, admit that it takes money to carry on experiments, to build equipment, shops and power plants, and to establish fields to sell the product, and for this reason, the financial side is entitled to the lion's share of the proceeds. But the engineer is also contributing. He has spent money, time and energy in schools and afterwards has spent year after year in gathering the experience, and now he puts all of these assets beside the capital, and should in turn receive a fair proportion of the profits.

The fairness of such a proposition appeals to every one, even the promotor or the manufacturer; at any rate, we judge so from the promises, which usually are made before the problem has been touched, and if the engineer would at this stage use ordinary business methods to protect himself and his interests, there would be no occasion for dissatisfaction. As it is, there are great numbers broken in spirit and of no good to this world, while in reality they should be useful and productive engineers.

Again I know of cases where the understandings were all clear and satisfactory, but they were only verbal, with or without witness. In both the cases disappointment followed, and even if the law protects the man if he has proper witnesses, the engineer in most cases will lose out, because he is financially the weaker party. Such procedures are usually so cumbersome and so expensive that very few engineers are able to avail themselves of this protection.

A great deal of misunderstanding also exists regarding the protection vested in our patents. So many think even today that a patent once allowed, would carry with it rights to manufacture whatever any of the claims may cover. This is not so, as items interwoven in the claims may have been patented before.

Just as numerous are those cases where an engineer feels justified to be the patentee, while the firm may claim it as their own. In this respect, I would again refer to the above mentioned Code of Ethics, and especially to the paragraph wherein it says:

"It is desirable that an engineer undertaking for others work in connection with which he may make improvements, inventions, plans, designs or other records, should first enter into an agreement regarding their ownership."

This would avoid all similar occasions of dispute. I once heard of a case where the engineer did everything. He made the sketches and the drawings, furnished the patent attorney all the details, followed up all the amendments, directed all the operations in the shops until the article was ready for the market, and even after that helped develop the field of sales; while on the other hand, the man who signed the patent did not do as much as the tramp who handed the lady a button with the request to sew a pair of pants on it.

Almost as bad, and possibly worse, in the means adopted, is the case which happened very recently. One of our colleagues made a very valuable improvement in the methods of production, so that very soon some shops were changed to get the benefit of the invention, but when the subject of patent protection was broached, a higher officer decided that the subject matter was not patentable, although great sums of money had already been invested. The result of this is a patent litigation, a new competitor, a sour engineer and a tinted reputation of an old and highly esteemed firm.

Both of these cases would have been avoided had the engineer paid heed to the paragraph just quoted.

With firms that look like family trees, the above notes hold true that much more, and if ignored, the engineer is liable to be overlooked when it comes to advancements. Quite often merit does not count for much in such an atmosphere.

I have purposely connected the different points with actual occurrences so as to make the matter clearer and more concrete.

This subject also received attention by the Second Pan American Scientific Congress in Washington, D. C., a few days ago, at which time I had the honor of being one of the delegates from our Society. There the subject was treated in a general, more abstract, yet systematic way, when Professor C. R. Mann, on the subject of Engineering Education spoke in part as follows:

From 1500 replies from all over the country the following summary was deduced:

1. The schools are strong in imparting technical knowledge.

2. The schools are neutral in their effect upon the personal characteristics of the students.

3. The schools are weak in making the proper connections between the school and the world's work.

In contrast to this stands the following summary of the elements of the ideal towards which engineers think the school should strive:

1. The development of character, self-reliance, independence, initiative, judgment, industry.

2. The imparting of technical knowledge and powers of scientific analysis.

3. The training in the application of theory to practice *in business sense* and in powers of expression.

The remarks made this evening are based upon actual observations made during the last twenty years and if they help to encourage the ascending colleague to watch the small and apparently unimportant details, and induce the experienced engineer to adopt stricter business methods in dealings concerning his own welfare, the author will be well repaid for his endeavors.

DISCUSSION

Mr. Samuel E. Duff: I am sure we thank our past president for that paper. He has touched on one of the great problems before engineers today, probably the greatest problem before engineers. The problem of getting men of high technical training is disappearing. The problem now is how to use well trained men, how to teach them to become an economic asset. The schools today do not teach the engineer his proper economic relationship to his work. Some magnify it, others minimize it. Further they do not teach him how his technical training can be made to increase his productive capacity, and the relation he is expected to bear to other forces in the economics of modern life. I think engineers should insist that their young recruits who have spent time and money for technical training should be given a working knowledge of practical economics.

In regard to the question of wages or earnings: I can say from my own experience that as long as I was an employee my income was always settled by other engineers. The employing engineers' ideas of wages were usually entirely controlled by the men who held the money bag. It is the business of the man who has money to keep it and he is not going to hand it out to the engineers until he is made to do it. If we want to encourage our junior assistants we must see to it that they are paid enough to live decently.

Mr. F. W. H. Clay:* I have been what might be called a silent member of this Society for some dozen years, and tonight had no intention of breaking that record; but the mental attitude exhibited by the past President and by the new President in their remarks suggest to me a thought that it might be well to express. I was educated as an engineer, but left the profession rather early to take up another line of work, and for that reason I would see the matter from a point of view not customary with the profession.

I would like to bring against you as a body the indictment of being too modest in your estimation of your importance to the community. I think that engineers are the most earnest, honest, and democratic set of men in the world; but they have the most extraordinary modesty as a class. (I hear murmurs of surprise; that is just why I want to point it out to you: the surprise is one of the results of your modesty, and shows that you have not sufficiently realized your importance to and your influence on the community).

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I was reminded, as I sat here, of an illustrative incident that occurred last summer. I have two small boys, and I was showing them a red-headed woodpecker hammering away on a dead tree. One said, "How can his head be so hard that he can do that," and the other one answered, "Don't you see, he eats so much wood!" —Now I am inclined to think that engineers generally, and this Society very often, are eating too much wood. That is, in our meetings the questions we discuss are so often distinctly and solely engineering topics that we forget we are also a body of influential citizens. Your President has just said that in the education of engineers there is a painful lack of teaching of anything other than the specific subject of their profession. The engineering profession taken at large includes that class of highly intellectual men who, as our President has just said make the earth a fit place to live in. I have often heard Dr. Thurston, of Cornell University, express himself on this subject, to the effect that an engineer should be given a much broader culture in order that he might exert greater influence as a citizen. When you come to think of it our entire material civilization is a matter of engineering; all our activities are based upon engineering; the engineer is the most important citizen of the country. I wish that engineers could realize that, and realizing it, force themselves forward to take a larger part in public affairs.

In other words, the engineer should cease to think of himself as a mere tool in the hands of the capitalist. He should remember that he is a creator, that he is an extremely important citizen, that it is his privilege to have an important voice in public affairs, and that it is his duty to exercise it. (This building code project, for example, is very largely a matter that should interest engineers and largely be governed by their views.)

One other point it might be worth while to mention: and that is in connection with Mr. Stucki's recommendation that engineers in the employ of corporations should disclose any inventions they make to their employers, and then proceed in some way to patent their inventions for the mutual benefit of themselves and their employers. Mr. Stucki is quite right in saying that the employee engineer's good faith requires him to disclose his invention to his employer, and he is right in saying the employer will own the invention only when it is a development strictly in the line of the employment. I think from my experience that the most satisfactory arrangement of contract respecting inventions is a contract by which the employee binds himself to disclose, and the employer has an option to buy the invention at any price offered by any outside party. This will afford sufficient protection for both parties. Fortunately it is not necessary to urge that the engineer almost invariably possesses a creative faculty, and may be expected continually to add to our stock of knowledge in the way of invention. I believe it should be the mental habit of the engineer to regard it as part of his function to improve the instrumentalities with which he works.

This fact that what the engineer brings to his employer is not merely his stock of knowledge and skill, but always the potential power of himself creating new inventions of use to the world, is one additional reason I would give why the engineer should be paid more highly than he is at present. The pay of the engineer is not entirely dependent upon the so-called "law of supplying demand" (—for there can not be a bigger supply than demand for skill and knowledge!). The engineer has been underpaid because he has not insisted upon being paid what he is worth. In the marriage of capital and engineering genius which is at the bottom of all great business enterprises, it has been too commonly accepted that the more important partner is the capitalist. I return to my first proposition that the engineer is too modest, and should insist upon being regarded as more important than he has been heretofore.

Mr. E. W. Henkele: In the Maintenance of Way Dept. of the Pennsylvania R. R., a young engineer, to qualify for promotion, must be under twenty-five years of age, a graduate of a well recognized college of Civil Engineering, and serve at least one year in order to prove his ability as a railroad engineer.

During this time he receives $64.15 per month as chainman, until he is put on the eligible list of rodman. On the Pennsylvania Lines East, there are about fifty rodmen who were promoted once: First year rodman, second year rodman and third year rodman. After serving three or four years as rodmen, they are sent to Philadelphia, where they are given a general course in railroad economics, accounting, bridge and building engineering. As vacancies occur, they are made Assistant Supervisor on branch lines, Assistant on Main lines, Supervisor on branch lines and then Supervisor on main lines. As Assistant Supervisor he receives from $115 and upwards per month.

The next promotion is Division Engineer on branch lines and then on main lines, which position pays from $200 up. There are a number of men who attain this position after being in the employ of the Company only ten years.

The next promotion is Division Superintendent at a salary of $500.00 and up.

The President of the Pennsylvania Railroad, according to the rules of the Company, must be a Civil Engineer and must successfully have held the positions mentioned above.

Hundreds of young engineers neglect such opportunities, which are offered, not only by the above Company, but also by other similar companies, such as Westinghouse Elec. & Mfg. Co. for electrical engineers, American Bridge Co. for bridge engineers, a number of steel companies in the Pittsburgh District for metallurgical and mechanical engineers, and also many opportunities for mining engineers.

The question is, why do so many men reject these offers? The answer is, in the majority of cases, the low salary in the beginning, which blindfolds him for a number of years, and then he sees there are "Some Details Often Neglected by Engineers."

MR. H. D. JAMES:* I wish to express my appreciation of Mr. Stucki's paper and to say that I entirely agree with his views. The paper has given me a new viewpoint as the author approaches the subject from a somewhat different angle than the one in which I have had experience.

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I feel that the compensation which the young technical graduate receives is less in many cases than required for him to maintain himself at the standard of living to which he has been educated. The compensation, however, has been fixed largely by the law of supply and demand. During the last ten years the technical schools have been graduating electrical engineers at the rate of 1400 per year; the United States census for 1910 lists 250 000 electrical engineers and electricians. With this rapid increase in the technical force our capital has not organized fast enough to make the best use of these men. During the business depression of the last three years, I have had a number of technical graduates with from five to eight years' experience, who have applied for positions and would have been glad to have had a salary of $75.00 a month.

When I left college in 1895 it was almost impossible for a technical graduate to obtain a position as he lacked experience and few employers were willing to give him the necessary practical training. Conditions have materially changed since that time and all of the progressive organizations using technical graduates are making more or less effort to train these men. During the last three years the National Association of Corporation Schools has been very active and is doing a great deal of good work. It now numbers among its members 100 of the leading corporations in this country.

These corporations have recently viewed the engineer from a different angle. They realize that the salary paid the men is only a part of the costs involved. The training these men receive during the first few years after leaving college represents capital invested in the man by the corporation and unless the training given the man is the proper kind and the results mutually satisfactory, the capital investment is lost and the man seeks other employment. This has resulted in many of the corporations having well organized educational departments and making a very careful selection of the technical graduate which they accept for training. When the man starts to work he is trained in a thoroughly systematic way by the best men in the organization, as anything but the best training is a waste of time and money.

It is well understood that the future of any business organization based upon an engineering product depends on the technical men in that organization and in order to compete, they must have some of the best men in the country. These men can only be obtained by thorough and systematic training. This point of view has justified the corporation with which I am connected in spending close to $50 000 per year in this educational work.

I agree with Mr. Clay that a great many engineers have not properly advertised themselves. On the other hand I feel that a number of these engineers are spending so much time in advertising that their engineering work is of secondary consideration.

MR. L. P. BLUM:* I was just going to make this remark; that the engineer, to a certain extent at least, evaluates himself. It has pained me at various times to come in contact with engineers who seemed to think that their own professional success depended upon how thoroughly they could criticise their professional competitors. I never come in contact with engineers who adopt this as their standard of professional conduct without thinking that they are injuring themselves as much as their competitors.

If we are going to succeed in engineering, if we are going to make men think more of engineering as a profession, we must refrain from undue criticism of our competitors. As long as their standard is any way fair, or in any way capable of being appreciated or praised, we should praise rather than condemn.

On the subject of the Pennsylvania Railroad standards, I might add just a little thought there. The same position which is to-day paying $64 a month was paying $45 per month twelve years ago. So there is a little advancement right there.

MR. D. M. HOWE:* Well, Mr. President, I have sat here and heard Mr. Stucki's very able paper, and the several comments on it, and I have heard one man accuse the Engineers' Society of extreme modesty. I have had a little experience in my time and I have seen some of them who were not so modest. One gentleman said that he would like to see the engineer branch out and know something about everyday business, and how to transact business with business methods.

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This is certainly a good suggestion and I surely will endorse it as it has been my experience of many years with the engineering profession, that the engineer is too technical and not enough of a business man. He is a man who goes up against great engineering problems and should surely have sufficient business training to carry him through with all these things.

I wish here to congratulate my good friend, Samuel Duff who has been installed as our President of this grand association, and feel sure that with a man such as he at the helm, there will be no lagging, as he is a man that will push things along as they should be.

MR. A. STUCKI: In closing this discussion, gentlemen, I have nothing else to add, nothing to criticize, and I am very pleased that so many details which the paper briefly touched upon have been brought out. The great interest shown by all of you does prove beyond a doubt that this subject is timely and of great importance.

THE ZINC SMELTER OF TODAY

By F. E. Pierce*

In considering this subject the large plants in the Pittsburgh District at Langloth and at Donora suggest themselves. The latter is, or will be, as large as any in this country, but there are several others of large size in the middle west, and some of the smelters in the gas districts in the southwest are to be reckoned with. There are also very large plants in Europe in which they are said to have departments embracing everything in the zinc industry which would include not only spelter, but zinc sheets, blue powder, zinc oxide, lithopone and sulphuric acid. It is not the purpose of this paper to discuss such comprehensive plants but to limit it to the ordinary understanding of the zinc smelter which usually produces only spelter and sulphuric acid. Even this is almost too large a subject for one paper and I can only hope to present some of the general considerations as affecting the business and the more important elements of the processes carried on with brief descriptions of the peculiar apparatus employed and the operation of the plant. Some lantern slides will be exhibited and show perhaps a little more clearly the matters which I shall attempt to describe.

In the first place the basis of the zinc industry is an ore supply. The ores are mainly sulphides known mineralogically as sphalerite or zinc blende, which carry approximately 30 per cent of sulphur. These ores cannot be smelted unless the sulphur is driven off. This process is called "roasting." The gas produced is principally a mixture of sulphurous acid gas and air and the laws of most states prohibit its free discharge to the atmosphere. The easiest way to dispose of it is to convert it into sulphuric acid, which is done by two processes, known as (a) Lead Chambers, and (b) the Contact Process The manufacture of sulphuric acid by itself is probably the one most important chemical operation we have, but it is such a vast subject and so well understood, or easily looked up, that we will not dwell on it at any length. This is particularly true of the chamber system, and the contact process is not used very generally in zinc smelters.

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Generally speaking zinc sulphide ores will carry about 45 to 60 percent of zinc and 30 percent of sulphur and one ton of average ore, 50 percent will yield about 850 lb. of spelter and one ton of what is known as 60 deg. sulphuric acid.

Now that zinc sells for 15c to 20c per lb. it is interesting to inquire why the zinc business has not been more generally exploited, especially by steel companies which could use a large part of the spelter and acid produced. There may be a great many special reasons but the main ones define fairly well the statistical position of the industry and are as follows:

First. The average price of spelter for a long term of years up to the present war was about 5.6c per lb. and the maximum variations were not very burdensome either to the producer or consumer.

Second. It was not difficult to contract for all the requirements any concern might have.

Third. It was difficult to contract for a satisfactory ore supply.

Fourth. The margin of profit in the smelting of zinc was very narrow.

Fifth. The common metallurgical practice in zinc smelting is highly technical and accompanied by many intricate difficulties. It is also apparently very antiquated and quite sure to be superceded by some process having the ear marks of this age of electricity.

These are some of the questions which any concern thinking of embarking in the zinc business would have to consider and a careful investigation was seldom encouraging. They probably answer the question of why the steel plants do not own their own zinc smelters.

Today is the golden age of the zinc business. Spelter sold last week for 17c per lb. A ton of 50 percent ore cost about $100. The working costs are about $15 per ton of ore, and

850 lbs. of spelter are to be obtained and a ton of acid. The spelter is worth about $135 and the acid about $40. The total receipts are therefore $175 and the costs $115, leaving profits of $60 per ton of ore. A two-hundred-ton-plant would return $12 000 per day or pay for itself in less than 8 months. In normal times it would be lucky to pay for itself in ten years.

Before going into details it may be well to define a few of the terms that will have to be used.

There is a fairly general understanding of what the word *zinc* stands for, but that *spelter* and *zinc* are one and the same so far as the commercial product is concerned is not generally understood.

To be definite zinc is one of the elements with an atomic weight of 65.4; is a metal, bluish white in color, has a crystalline fracture, tarnishes on exposure, has a specific gravity of about 7, weighing about 435 lbs. per cu. ft., has a tensile strength depending on its structure and purity of between 3000 and 10 000 lb. per sq. in., is quite brittle when cold, quite malleable and easily rolled between temperatures of 250 and 300 deg. Fahr., and brittle again at 400 deg., melts at 790 deg., and boils at 980 deg. When vaporized it readily burns to zinc oxide.

Spelter is the commercial name for metallic zinc. Ordinary slabs of spelter weigh from 45 to 70 lb. and measure 7 in. to 9 in. wide, 16 in. to 18 in. long and 1 in. to 1¾ in. thick.

The ordinary grades and specifications for spelter are as follows:

High Grade: Lead not over 0.07%
Iron " " 0.03%
Cadmium " " 0.05%
Free of Aluminum
Sum of Lead, Iron and Cadmium not over 0.10%

Intermediate: Lead not over 0.20%
Iron " " 0.03%
Cadmium " " 0.50%
Free of Aluminum
Sum of Lead, Iron and Cadmium not over 0.50%

Brass Special: Lead not over 0.75%
Iron " " 0.04%
Cadmium " " 0.75%
Free of Aluminum
Sum of Lead, Iron and Cadmium not over 1.20%

Prime Western: Lead not over 1.50%
Iron " " 0.08%

Zinc dust or "blue powder" is very finely divided metallic zinc superficially oxidized and is produced by the sudden cooling of zinc vapors. It is used in the arts where a strong reducing agent is required.

In roasting zinc sulphide ore (ZnS) zinc oxide is produced and the loss in weight is approximately 15 percent. In other words, 100 tons of green or raw ore will when roasted result in about 85 tons of roasted ore.

The fundamental principle on which rests the smelting of zinc in the ordinary spelter or distillation furnace is that zinc oxide plus carbon plus a certain number of heat units equals the metal zinc plus carbon monoxide.

In theoretical quantities 100 lb. of ZnO plus 14.7 lb. of C plus X B. t. u.'s equals 80.3 lb. of Zn plus 28 lb. of CO.

In general the carbon or coal mixed with the ore is fine anthracite coal, coke or a non-bituminous coal and is commonly called charge coal or reducing fuel. A great deal more is necessary than theory calls for. The amount is usually about 50 percent of the ore by weight.

The excess is required because the operation is not efficient and because an excess of coal prevents to some extent the formation of troublesome slags.

If the zinc vapors come in contact with oxygen or air they burn at once forming zinc oxide again. The operation therefore has to be conducted in a way to prevent this.

The only commercial method which has been developed for carrying on this reaction is by using a vessel made of clay which will be reasonably non-porous, withstand the heat, resist the corrosion of the slag and be within the limits of cost. These vessels are called retorts or muffles, retorts when circular in cross section, and muffles when oval.

Retorts are generally used in this country and a common size is 8¼ in. diameter and 4 ft. 4 in. long, inside measurements. The walls are 1 inch thick and the butt about 2 inch thick.

The size is determined by several factors. The time function requires that for a given interval, usually about 20 hours, when the smelting is actually going on, the largest possible charge may be fully worked off. The diameter of the retort is limited because if very large the central portion will not become heated.

The length of the retort is limited because the clay under the conditions in the furnace has only a limited tensile strength and with the cross section of a tube about 9 in. diameter, the limit is nearly reached with a span of about 4 feet.

The muffle or vessel with oval cross section would seem to be the one to meet these conditions best but the difficulty of making muffles relatively as good as retorts coupled with other constructional difficulties has thus far operated to prevent their adoption in this country to any extent.

The gas generated by the reaction with the zinc vapors has to escape but the zinc must be condensed. If the zinc vapors are cooled suddenly the zinc will not condense as metal but as blue powder. More or less blue powder is always produced.

Some contrivance therefore has to be used to retard the escape of the gas and to condense the vapors. This is also a clay vessel and is called a condenser. It is of a truncated conical shape about 18 in. long with walls about ⅞ in. thick, the hole at the small end about 2½ in. diameter and the large end made to fit easily in the end of the retort. This hole is luted up or stuffed with fine hard coal to dam the molten zinc and further control the condensation. The proximity of the condenser to the retort keeps it hot enough to prevent the sudden cooling of the zinc vapors but the latter are cooled sufficiently in passing through the condenser to be intercepted as molten zinc.

The retort as installed in the furnace is at an angle ot about 12 to 15 deg., open end downward, to facilitate charging and discharging and to drain itself. It is mudded into the front of the furnace by a thin clay wall.

The condenser is placed at the end of the retort with its axis parallel to the floor, and is supported in place by an attachment on the furnace called a grasshopper or a brickbat. The joint it makes with the retort is closed with loam or coal. The heat of the furnace soon burns this or crusts it up and the condenser is quite firmly attached to the retort.

This is the real element which is the basis of the zinc smelter. Everything done in the plant is to the end that these elements may continue in operation, as for instance, the arrangement of these elements in the furnace, the convenient arrangement of the furnace, the buildings and in short the plant layout are all to keep these elements working.

We will now consider the manufacture of these retorts and condensers or the pottery, then the furnaces, then the ores and their roasting, mixing with other materials and handling. The operation and labor on the furnaces, and finally the organization required to operate the plant.

In discussing this question we will consider as an example a plant treating about 200 tons of ore per day producing about 200 tons of acid per day and 85 tons of spelter. Such a plant would probably consist of four Hegeler roasting furnaces, four acid units, and eight spelter furnaces.

To return to the retorts and condensers, these are made of mixtures of grains of burned clay, and plastic clay. The grains otherwise known as sand, grog or chamotte are in the case of retorts ground fire brick of good quality or calcined flint clay, screened to a size of about ⅛ inch or a little less; for condensers, old fire brick, retorts or condensers, screened to a size somewhat coarser.

The plastic clay for retorts is in nearly all cases the well known St. Louis clay of which the better run of the bed is selected.

Every spelter man has his own pet formula for his retort and condenser mixes but the proportions of grog and plastic clay are approximately half and half. To this is sometimes added graphite or coke dust to an amount of 10 percent more or less.

The process of mixing and manipulating the materials prior to making the retort or condenser is similar to that for the manufacture of brick in the case of the retorts. The ingredients are mixed, pugged several times, being allowed to temper or rot between times until finally a large ball, wad or ballot is produced which is inserted in the retort machine.

The peculiar apparatus used in the pottery of a zinc smelter are the retort press and the condenser machine..

The retort press is operated hydraulically and the lantern slides show the details better than any description I could give. The original retort press was the invention of Dorr, a Belgian engineer. It was very ingenious. Prior to this retorts were molded by hand or by what is known as the tile machine. The latter which is only a vertical pug mill forms a clay pipe, of the proper diameter which is cut off at the proper length. The butt is inserted and molded in. The problem was to design a machine to make a retort butt and all in one operation, which Mr. Dorr accomplished.

Many improvements have been made on the first design both by German and American Engineers.

A retort machine can easily make 25 retorts per hour or 200 in an 8-hour day. The machines are quite expensive but they are indispensable for a large plant.

When started the pressure to form the butt may run up to 2500 to 3000 lb. The pressure is released and cap unclamped and removed and the press started again. The retort is pressed out and the pressure may vary between 1500 and 2000 lb., depending on the stiffness of the clay and the conformation of the passage through which the clay is forced. When the retort is of full length it is cut off by a wire, a wooden cradle stood against it and the two tipped over. They are placed butt downward on a truck and taken to the drying room, where the retort is stood, butt down, to remain until dry. Two men operate a press, but several men may be required to handle the retorts made.

In making condensers the materials are pugged once, allowed to rot for a day or two, then pugged a second time and the clay balls passed to the condenser machine.

The condenser machine is the invention of American engineers and is very ingenious: It consists of a revolving table with several condenser molds standing in it. A vertical shaft with a reciprocating movement has a mandril on the end which is the core. Clay balls are put in the molds and when centered under the mandril the latter is forced while revolving into the clay ball and the condenser formed. In one form of machine the molds are made to rise. The machine can easily make 100 to 150 condensers per hour. Two or three men work at the manufacture of condensers.

It is not such an expensive machine as the retort press and is also indispensable, in a large plant.

Besides the retort and condenser machine, and the pug mills, the pottery has crushers, rolls, elevators, screens, storage bins, etc., and the layouts have to provide for all these and also special apparatus, conveyors and the like to handle the materials and the manufactured vessels.

The drying rooms for retorts have to be well insulated and tight. They usually have wooden slat false floors under which are steam pipe coils; they also have a well arranged system of ventilator pipes. The drying of the retorts has to be done most carefully and takes about four to six weeks. The rooms may hold almost any number of vessels, but sizes holding two, three or four days make are not unusual.

In Europe quite extensively and in one large plant in this country, a system of forced and tempered circulating air is used for drying retorts. Such systems would seem to have considerable merit and deserve more careful study.

The drying of condensers requires less care. They stand on the floor over night, are crimped the first thing in the morning and then stood on racks on the main pottery floor and air dried for about ten days, which is sufficient.

The condensers after drying are put in the condenser kilns and burned for 48 hours. It may take five or six days to fill, burn, cool off and empty a condenser kiln and the size and number of the kilns will depend on the size of the plant. A kiln holding 3000 is not unusually large, and for the 200-ton plant using possibly 900 condensers a day about three of such kilns would be required. As most spelter plants manufacture their own special brick it is not uncommon to have an extra kiln for other condensers and for brick. The burned condensers are removed from the kiln when cooled off and placed in the condenser storage building, which may hold as much as half the stock of condensers on hand.

The retorts are taken from the pottery drying rooms, usually in special covered cars, directly to the retort kilns in the spelter furnace building. There are commonly two kilns for one furnace, the one cooling off and being filled while the other is being fired. This also gives some margin for excessive retort loss, when this occurs, because it is possible to use a kiln every day. The retorts are burned for about 18 hours only. They are taken from the kiln when red hot and put in the spelter furnace, the furnace men having special tools for doing this work.

The condenser and retort kilns are fired with natural gas or with coal.

It is common practice to have 6 or 8 weeks' stock of retorts on hand and 3 to 4 weeks' stock of condensers.

With the plant in question with eight spelter furnaces with 800 or 900 retorts each the life of the retorts with the ore charge will not often exceed 30 days; not often be less than 20 days. The retorts charged with blue powder may last 60 days. Taking the average life of the retorts in a furnace it would be about 30 days and at this they would all be changed each month. This means about 250 per day and with imperfect vessels and breakage may easily amount to 300 per day. The stock of retorts may be about 15 000.

The average condenser may be expected to last about 10 days, or be renewed three times every month. This means about 700 a day and with defective vessels and breakage may amount to 900 per day. The stock of condensers on hand may be 20 000.

In the pottery the clay used in mudding up the furnace is made up as well as that used for the manufacture of brick and other purposes. For mudding up the furnace the clay used for condensers is commonly employed.

The success of the pottery, of the zinc business, depends to a great extent on the specification and selection of the proper materials for the manufacture of the retorts and condensers and their subsequent care and handling. From what has been said it will be observed that by itself the pottery is a considerable business.

SPELTER FURNACES

The types of spelter furnaces used in representative plants in this country are:

1. The Hegeler producer fired furnace.
2. The Natural Gas furnace (Hegeler type).
3. The Regenerative furnace (Siemens or Neureuther).

The Hegeler and Natural Gas furnaces do not differ greatly in appearance from the top part of the Regenerative furnace. All have middle walls with ledges for supporting the butts of the muffles and front walls made of pillars and plates, held in place by buckstays.

The Hegeler and Natural Gas furnaces have two arches, making really two furnaces in one block, back to back.

The Hegeler has one producer firing both sides. The gases enter one end, pass through amongst the retorts and out of the other end to a waste heat boiler and thence to the stack. The air is admitted by small pipes at intervals along the furnace where the buckstays occur. Until recently the air has not been preheated, but means for doing this has been devised in connection with mechanical producers, and satisfactory results are said to be obtained. The ordinary Hegeler producer is a large rectangular steel box lined with fire brick, parts of it water cooled, and blown by steam jets. It is designed to utilize the largest possible amount of the sensible heat of combustion.

The regulation of the furnace is done by the firing of the producer and the admission of air. The furnace operates continuously, which is a favorable condition. The fuel ratio is high and may be 1.5 to 2.00, but much heat is recovered in the boiler, and if all the steam can be utilized the net result is said to be very low.

The natural gas furnace is really a modification of the Hegeler. The gas and air enter the furnace at intervals along the front, burns amongst the retorts and waste gases pass out of the stacks at the end. These furnaces also are continuous in operation. They are only adapted to natural gas.

In the Siemens and Neureuther furnaces the gas and air pass through the regenerators under the furnace up through riser passages to ports in the middle wall and enter the retort chambers or laboratories as they are called, burn amongst the retorts pass upward over the middle wall and out through the ports and regenerators on the other side. The currents are reversed at intervals of about a half hour and the operation of the furnace is intermittent. This is not a favorable condition for the best work, but it saves fuel. The full ratio on this furnace may be unity or less. Any good gas producer may be used on this furnace.

The banks of retorts in all types are four, five or six high, the practice of late leaning to five high or six high.

The furnace floors in coal plants are usually elevated above the ground level. This is necessary with the Siemens furnace to provide the head room required for the regenerators which may be 12 to 20 ft. For the Hegeler types it is advantageous because the residues from the furnace, when drawn, first fall into hoppers from which they are dumped into cars and removed. Natural gas furnaces are most frequently on the ground level and the tunnels are in excavations, but where sloping ground occurs this can be utilized to advantage. This also applies to the Hegeler furnace.

ORES AND THEIR TREATMENT

We now come to ores and their treatment. Zinc ores broadly are of two classes: oxidized and sulphide. The oxidized ores are ordinarily easily reduced and play an important part in the smelting operation, but they are relatively of small tonnage and are used mainly for special purposes, as a front charge, or for mixtures to obtain a more reducible or nonslaging charge.

The sulphides are the basis of nearly all the spelter produced. They are from the well known districts of Joplin, Missouri, Wisconsin, Montana, Utah, Colorado, Mexico, Australia —almost everywhere.

In addition to the zinc they may contain 2 to 10 percent of lead, 2 to 15 percent of iron and varying percentages of silica, lime, etc., and they may carry in small percentages silver, copper and gold.

In almost all cases the ores are resulting concentrates from the run of mine of the district in which they occur.

It is of course always possible that lump ore may be received at the smelter in large tonnages. The smelter therefore has to have a crushing department, which may be of considerable size and rarely is less than 100 tons capacity in a large plant.

The jig and table products from Joplin and Wisconsin are granular, about 1/16 in. size more or less, are more easily handled and worked.

With the flotation products, 40 to 100 mesh and finer, the roasting difficulties in muffles increase tremendously. The ores are very difficult to handle. Yet these ores are coming to represent a very considerable percentage of the available supply and have to be dealt with.

In the 200-ton plant we have considered there may be five or six cars of it coming in every day. It may carry a lot of moisture, 10 to 15 percent. It will have to be sampled carefully and it must be dried before it is roasted. Probably at least two months' supply or 12 000 tons should be on hand. The ore seldom costs less than $25 per ton, and may cost more than $100. The necessary ore handling and storage equipment for a zinc smelter has to be a considerable proposition in itself, and the ore purchases and carrying charges involve almost as much capital as the cost of the smelter.

In the gas districts ores are roasted and the sulphur gases are wasted. Zinc ores with 25 to 33 percent of sulphur if set on fire will burn of themselves under proper conditions until the sulphur is reduced to 6 or 7 percent. This is not low enough for smelting. Some sulphur is bound to remain in the roasted ore from its combination with lime forming calcium sulphate. This cannot be helped. Beyond this the sulphur should not exceed 1 percent and the lower the better.

To roast down to this limit, extra heat must be introduced in the furnace. The furnaces in the gas districts are called Ropp, Brown, Capeau and others. The principle in all is to start the sulphur in the ore burning, to rabble, or stir it up as often as possible, and as the fire begins to die out to keep the heat up so that the sulphur continues to burn off, until the ore is completely roasted. Natural gas is used for this in some districts and it is not difficult to roast the ore to a low sulphur content, but the sulphur and fire gases are all mixed together.

To make sulphuric acid the fire gases must be kept apart from the sulphur gases. These should have an SO_2 content of 6 to 7 percent, if possible.

The Hegeler roasting furnace keeps the sulphur gases by themselves, but it does not keep them up to an even percentage of 6 or 7 percent. They vary a great deal and while some plants claim to maintain an average of 6 percent, others where good roasting results are obtained and accurate records kept, do not maintain an average of over 4 percent. It is, however, possible to use these gases to make acid and quite successfully.

The Hegeler roasting furnace is really two furnaces side by side consisting of superimposed hearths about 6 feet wide and about 80 feet long. There are usually seven hearths and the ore is charged at the top at one end through a bell and hopper and drawn through by rakes attached to rods operated by machinery at the opposite end of the furnace. The three lower hearths are heated externally by gas hearths and by producer gas or coal fires, the ore thus being kept hot and the sulphur burning. The rods are passed through the furnace, hooked onto the rakes, which are resting on multiple deck turntables by the man at the end of the furnace. When hooked on and everything is ready, he blows a whistle and the machinery is started by the man at the other end. The ore charged is raked through and spread over the top hearth and the construction of the rake is such that it moves along with it to the far end of the hearth about the same amount of ore that is charged. This falls to the hearth next below through drop holes. The rake passes on out of the furnace to the turntable on the other end. The rake on the hearth next below travels in a similar way but in the contrary direction. This goes on until the bottom hearth is reached, when the ore is drawn out of the furnace and passes over a chute to a car standing there for the purpose, or to a hopper from which it is drawn into a car. The turntables are revolved and the rakes passed through the other side of the furnace to their first position. There are patented arrangements which permit of a furnace being operated by one man at each end, so-called "one man control," but ordinarily two men are required at each end.

One side of the furnace is raked approximately each hour. The charge of ore each time is a little over 4000 lb. It takes between three and four days for the ore to pass through the furnace.

Hot air is introduced in the furnace and sometimes an air heater is used for this purpose.

The furnace is about 17 ft. wide, 25 ft. high and 85 ft. long. The rods pass backwards at each end in rod alleys about 100 ft. long.

There has to be a space along the side of the furnace for scaffolding or a chipping car from which workmen may chip the crusts of zinc ore which accumulate on the hearths. If these are not chipped out the rakes stick and there is serious trouble.

The gas producers are placed along side or at the ends of the furnace between the rod alleys.

The space occupied by a furnace and building is approximately 40 ft. wide and 325 ft. long. The whole arrangement does not lend itself to a real clean cut ore-handling scheme.

The green ore has to be elevated to the top of the furnace. Sometimes it is held in overhead storage bins near the crusher, drawn from these into cars which are trammed on a trestle to the furnace and charged. Sometimes it is handled in cars on tracks on the floor level. Then it is dumped in the boot of an elevator which hoists and discharges it to a spout leading to the hopper and bell. This can be operated by the workmen from below.

The roasted ore comes out red hot. There are at times some lumps in it and arrangements are made to screen these out, preferably when drawn from the kiln, but also over the storage bins. These lumps are crushed and returned to the furnace. Sometimes the ore is not perfectly roasted and this ore has to be kept by itself and returned to be reroasted.

The roasted ore generally has to be cooled before it is mixed in the furnace charges. This is sometimes accomplished by letting it stand in the ore cars or passing it through coolers or cooling bins, or at once to large bins which are filled up and allowed to stand until cool. In one plant hot ore is put in the mixer and water run in at the same time. It works well.

An important factor in handling zinc ores is to cut down the number of times it is dumped and avoid dusting losses. This is most important with flotation and fine ores, because the dusting losses are considerable.

There are a minimum of six handlings in the ore handling and in the roasting departments and this may mean a loss of ½ or 1 percent of the ore.

It may also have to be crushed, dried and handled three or four times more with this treatment. It may pass through cooling bins and be handled twice more. These operations involve a proportionately greater loss.

The most serious result of this dusting loss is that the workmen have to breathe the air and thus are liable to become poisoned from the lead contents.

The European plants are most careful as regards this and have to be so because of the very strict laws on the subject. Our own laws are much more strict than they used to be.

The lantern slides show the furnaces, the turntables, the kiln machinery, certain ore bins, etc.

THE MIX HOUSE

The roasted ores are stored in bins from which they may be drawn out in measured quantities to make up the mixed charge for the spelter furnace. The ingredients in this mixed charge are the ore of one or more kinds, the reducing fuel, possibly a little water and perhaps the skimmings and other materials returned from the furnace. Excepting the water which is added at the mixer, all these materials are in bins and weighed out in a weighing larry or a crane one after the other in one trip or separately and taken to the mixer. In a small plant workmen with barrows may make up the charge.

Sometimes the mix for many furnaces, possibly all, is the same and it all goes to one or more bins, from which it is measured out and taken to the furnaces. It is better practice to make up the charge for each furnace separately.

The mixer is usually a large sized concrete mixer of any good pattern and discharges into a skip or elevator or into the charge car itself.

In the gas district the mixed charge is usually elevated and dumped into the charge car which is trammed to a transfer car. The transfer car is moved opposite the track in the furnace building for which it is intended. This may also be the case with the Hegeler furnace and also the Siemens, but, owing to the greater elevations of the furnace floors this work has usually to be done on trestles.

The charge cars may be quite large affairs. With a furnace of 25 tons capacity there may easily be 80 000 lb. of charge to handle. This will weigh rather less than 100 lb. per cu. ft. and there will be at least 800 cu. ft. of material per furnace to be held in charge cars.

There may be not less than four cars per furnace holding 200 cu. ft. each. The objection to these cars is the floor space they occupy in a furnace room, especially if there be more than one furnace in a building. They are very much in the way for handling retorts and condensers and other materials needed in the furnace rooms.

One method to avoid this is to transport the charges on a high line trestle in larry cars and dump the charge on charging tables on the furnace floor or to bins supported by the roof trusses of the building. The charging tables are on wheels and moved up to the furnace, when it is charged. With overhead bins the charge is drawn to small charge cars in front of the furnace. Both methods have been worked out satisfactorily.

With the Hegeler furnace there is one and with the Natural Gas furnaces there is one or at most two furnace blocks in one building. The transfer track at one end, allows the charge cars to be pushed to the other end of the tracks and they are not in the way.

HANDLING OF MATERIALS TO AND FROM FURNACES

In addition to the retorts and condensers, furnace mud and charge there has to be taken to the furnace buildings, the luting coal and the producer coal. The latter will probably be handled by standard gauge cars as the tonnage involved may be over 300 tons per day. The other materials are commonly handled on narrow gauge tracks.

A summary of the materials to be delivered daily is as follows, in the 200-ton plant:

Retorts and Condensers,	25	Tons
Furnace Mud,	3	"
Luting coal,	20	"
Charge, inclusive of skimmings, etc.,	325	"
Total,	373	Tons
To which must be added the producer coal,	300	"
A grand total,	673	Tons

A summary of the materials removed from the furnaces:

Old retorts and condensers,	20	Tons
Spent Mud and Clay,	2	"
Furnace Residues,	135	"
Metal,	85	"
Skimmings, etc.,	25	"
Producer coal ashes,	60	"
	327	Tons.

This is a considerable proposition, primarily a handling of materials question but all dependent on the successful operation of the retorts.

ON THE COAL CONSUMPTION

In the gas district this question does not exist, and its absence contributes very largely to the relative simplicity of a natural gas smelter.

As already stated with the Hegeler furnace the coal ratio may be 1.5 to 2.00 or in other words there may be required 300 to 400 tons of coal to be handled for the plant in question.

If we add to this the reduction fuel of 50 percent of the ore or 100 tons and the luting coal of 20 tons and also the fuel for roasting there are required for the smelting operation between 450 and 550 tons, or 2¼ to 2¾ tons of coal for each ton of ore, or for the 85 tons of spelter produced 5 to 6 tons of coal.

With the Siemens regenerative furnace the coal ratio should be unity or less and the total coal should not exceed 360 tons or 1.8 tons per ton of ore or about 4.2 tons per ton of spelter under the most favorable conditions, apparently very wasteful; but this condition requires that the zinc smelter shall be located so as to obtain the cheapest possible fuel.

With the power credit obtained by using waste heat boilers with the Hegeler furnace a net coal consumption may be reduced to low figures, but I have no accurate information on this question, and the installation of the waste heat boilers and of a considerable electric power plant adds to the expense of the plant.

If Siemens furnaces are used boilers will be required in a power plant both to provide steam for the gas producers and power for running the plant, but the power requirements of a zinc smelter are small, even with a contact acid plant, and should not exceed 1000 boiler h. p. or 1000 k. w. per hr. for a 200 ton plant.

LABOR ON THE SPELTER FURNACE

In the gas district they have for a furnace block of 640 retorts, the standard for the district, about 24 men. There are foremen for the furnace department, cellar men who handle the residues from the furnaces and other men who work on several furnaces. For a 6-block plant there would be an average of 23 or 24 men to a block. The names of the positions occupied by the workmen are peculiar to the zinc business. There are firemen, chargers, men behind the car, bumpers, blowouts, chiselers, condenser cleaners, metal drawers, charge tenders, stuffers, and usually assistants to these. They do not all do one thing, but the work around the furnace is divided in what has come to be considered an equitable way and certain rates of pay accompany certain jobs. It would take a long time to tell what each man does. The work starts early in the morning,—about four o'clock. The retorts where necessary are changed. The metal is drawn for the last time. Then gas and air are shut down. The condensers are taken down, chipped of crusts and metal that stick to them, as well as the throats of the retorts. The blue powder which has been made is collected and moved to the stack end of the furnace. The residues are blown out of the retorts with a jet of water or of steam, or scraped out. A shield is moved along the front of the furnace and the water or steam pipes inserted through a hole opposite the retort and the water turned on. This forms steam in the retort which is thereby quite thoroughly cleaned. The shield protects the workman. The blowing out begins at the end away from the stack and proceeds to the other end.

Mention must be made here of a discharging machine which has been tried out and is in successful operation in several plants. A series of scraper chains are moved in a bank of retorts and the residues are scraped out from as many as ten retorts at a time. The saving in time and labor and the resulting cleaner retorts are the promising results of this invention.

After the cleaning out, the chargers or other men who do the work come along with the charge car and shovel in the charge. This work is hard and requires great skill. All the charge is shoveled in with a peculiar elongated and narrow scoop with which the charger at a distance of several feet can project about ten pounds of it into a hole 8 inches in diameter. He does it and without spilling a great deal.

The charge is put in for about two-thirds of the furnace and the collected blue powder and some charge put in in the remaining third. The top rows have to be charged from tables or platforms on the charge car.

After the charge is placed the condensers are set and loamed up, everything is cleaned up and part of the men go home. The furnace is said to be set up.

The work of charging is completed about 8 A. M.

To relieve the workmen some plants are equipped with air blasts, which blow on the workmen while charging the furnace, or he may by taking a step stand in the cooler air and be refreshed. This is a great help, especially in hot weather. The heat in front of a furnace is intense.

Several kinds of charging machines have been invented and tried out. They are said to be successful, but they have not been introduced to any extent as yet.

While the furnace is being charged the fireman has gradually brought the heat up. This continues until about noon, when the temperature will be about 1100 deg. Cent. Thereafter it is slowly increased until it is about 1300 deg. Cent. at 2:00 A. M.

The work on the furnace after it is set up outside of the regulation of the heat consists of very careful attention, locating broken retorts, and drawing the metal. The little bluish flames or yellow if salt is used at the condensers are a certain indication of what is going on within, and the appearance of the whole front to the experienced eye tells at a glance how the furnace is coming on.

A large furnace at night working well is one of the real sights in a metallurgical plant.

After a time the condensers are stuffed and spiessed and the free escape of gas throttled down.

The drawing of metal begins at 4:00 P. M. from the retorts charged with blue powder and the first draw on retorts with charge about 5:30. The second draw begins on blue powder about midnight and ends on charge about 3:00 A. M. After the day crew comes on the last draw is made by all the men with hand ladles.

The operation of the Hegeler furnace is similar to the natural gas furnace except that additional workmen are required for the producer. On a large furnace the crew may be as many as 34 men.

The operation of the regenerative furnace is quite different. The furnaces are usually scraped out instead of blown. The blue powder is put in the top rows. The furnace is divided into a number of sections and gangs of men called machines work on these. The number of men is about the same as on the large Hegeler furnaces, but the several gangs on each side of the furnace each have a certain number of retorts to attend to. The middle or bottom rows are charged first and the top rows with blue powder last.

After the furnace is all set up the succeeding work is not very different. The operation is not quite as clean cut as that of the Hegeler furnace, but the results obtained are probably as good.

There has been developed recently a process for briquetting the charge, introducing some saving of labor in charging, but mainly the possibility of carrying a much heavier charge, with relatively as good recoveries. This has been tried out on regenerative furnaces and has probably given that furnace a stride in advance of the Hegeler furnace.

Great attention has been given of late to the treatment of furnace residues, principally because of the silver values contained in them. A spelter furnace can be worked so that 60 to 70 percent of the silver in the ore will remain in the residues. This may be 6 oz. to 10 oz. per ton of residues. About 50 percent of the lead in the ore will remain. This may amount to 50 to 100 lb. per ton of residues. They will also contain about 35 percent of carbon. If a lead smelter is nearby they can be mixed with other materials and used directly in the lead furnaces.

They are quite bulky and therefore will not stand a long haul or heavy freight charges. If a lead smelter is not nearby there may be no profit in treating them, unless they are reduced in bulk.

Mr. Archibald Jones when at Bartlesville worked out a systematic arrangement of the old process of heap roasting to accomplish this. The residues will usually burn without the addition of fuel. The heat is under control and most of the lead and silver remain. The zinc is volatilized and part of it deposits in crusts on the surface of the piles. These crusts can be separated and recovered. The residues are much reduced in bulk and the process is said to work very satisfactorily.

The residues will carry about six percent of zinc. They can be profitably treated in an ordinary Wetherill oxide furnace and zinc oxide recovered. This process is better adapted to the treatment of residues where the silver values are low for much lead and silver are driven off in the oxide furnace.

The metal made at each furnace is taken to the metal storage and kept separate. It is carefully sampled and held for shipment. Sometimes the different draws are kept separate.

Allusion has been made to the great danger from lead poisoning, and the increasing strictness of laws governing the conditions. All companies are only too glad to do anything to contribute to the health of the workmen, and diminish this kind of trouble. Great attention is being paid to well-arranged change houses, eating rooms, and everything to improve the working and sanitary conditions in the plants, and the results are most satisfactory.

The large zinc smelter is ordinarily quite complete in plant facilities. Besides the transportation and other material handling equipment, and the power plant producing steam, compressed air, and electric power, there should be an abundant water supply both for mill purposes and for drinking. A good system of drainage should be provided and in many states an approved system of sewage disposal is required. The power and light cables, telephone and fire alarm lines connect all parts of the plant to the power-house and to the head office. All this equipment practically necessitates a machine shop, part of which is given over to electrical repairs. There is usually a carpenter shop, possibly a pattern shop. Foundries are not usual. There is frequently a plate shop, also equipped to repair tank cars.

The plant manager or superintendent will usually conduct the administration from the head office in the plant. All plant records, such as the timekeeping, construction and operating accounts and other bookkeeping, together with reports and costs are commonly made up and kept there.

The superintendents or foremen of departments commonly have their own offices close to the work.

Taking all the plant as one whole organization there may be a large number of men, but most of them have specific duties, which simplifies the managing of the plant considerably.

Frequent reference has been made to the Hegeler spelter furnace and the Hegeler roasting furnace. These were invented by Mr. Edward C. Hegeler of LaSalle, Ill., who died in 1910. He was one of the owners of the Matthieson & Hegeler Zinc Co. of LaSalle, Ill. Mr. Hegeler was identified with the zinc business in this country for 50 years, and had more to do with establishing and developing it than any other one man. A record of his work with his numerous inventions would be a most illuminating story of the growth of the zinc smelter. It is to be hoped such a record may appear in due course. It is fitting and proper to remark that there is hardly anything of importance about a zinc smelter but which has been improved by his handiwork. A great many men now occupying positions of importance with other companies started their careers with his company. When any proposition is made in the way of a departure from accepted practice sooner or later we are confronted with the statement that Matthieson and Hegeler do it thus and so. I think that we may say that Edward C. Hegeler was the father of "The Zinc Smelter of Today."

There are many things in the air. The electric zinc furnace, electrolytic zinc, etc. They may be the coming things, and in a few years the zinc smelter as known to us may be a thing of the past. The time has not come to say.

This paper already is too long and I may not take them up at greater length.

In preparing this paper I have been greatly helped by Mr. M. F. Chase of Chicago, and several other friends closely identified with the zinc business, who prefer not to be mentioned, but I take this opportunity of gratefully acknowledging the valuable assistance given me. I am also indebted to the Engineering and Mining Journal for the use of several illustrations from which lantern slides have been made.

DISCUSSION

Mr. Joseph Breslove:* I notice Mr. Pierce did not mention the Hegeler mixer. This is a cubical box somewhat in the form of the well-known concrete mixer. Steam may be admitted at will through a central trunnion, and the box revolved by power. This mixer is used in two or three very large plants, and I would be very glad to know something about its function.

The Author: I am not particularly familiar with the Hegeler mixer except that it is a very large cubical mixer and not very different from the cubical concrete mixers that have been used for a great many years. I do happen to know that the Hegeler Zinc Company at Danville uses a cubical mixer. It is very large. They put hot ore in and use water at the same time to cool it.

Mr. F. F. Farnham: I would like to ask a question. In Pittsburgh we are more or less interested in residual zinc-bearing materials. What would be the effect on the smelting operation if the zinc oxide used contained small amounts of chlorine and small pieces of iron, such as nails, nuts, bolts, etc.?

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*Engineer, Allis-Chalmers Mfg. Co., Pittsburgh.

THE AUTHOR: I cannot tell you all of the objections to chlorine, but it is quite objectionable. It carries away zinc in the form of zinc chloride, which cannot be collected. I understand this is the principal objection, but there are many others. The smelting of zinc with iron in it is very objectionable. If too much iron is present it is not readily smelted. Specifications for standard spelter limit the amount of iron it may contain. In zinc drosses or ashes, iron is very objectionable whether the drosses are resmelted or used in chemical processes.

MR. F. F. FARNHAM: Will the iron pass over into the condensers with the zinc?

THE AUTHOR: A little of it.

PROF. H. C. RAY:* Why is salt used in zinc smelting? I have never found a satisfactory answer to this in any reference.

There are several other matters of which I should also like to speak. The first is the reason for the use of retorts rather than mufflers. There are three types of distillation vessels: (1) The large muffle-shaped vessel used in upper Silesia; (2) a medium-sized muffle used in Prussia; and (3) the relatively small vessel used in the so-called Belgian process, which is circular or elliptical in shape. These shapes are not at the present time limited to any one section of the world, although the Belgian retort is used almost exclusively in the United States. The reasons for the differences in shape were due, as Mr. Pierce says, to the greater strength of the retorts as compared to the muffle on account of the generally smaller area of cross-section and, therefore, smaller load. The most important reason, however, I believe, was due to the difference in the character of the ores treated. In Silesia the ores were generally purer and coarser and contained a greater proportion of oxidized ores and, therefore, much more easily reduced than the less pure, more finely divided sulphide ore of Belgium and the United States. Hence, in the former practice, the matter of heat penetration and the expulsion of the reduced zinc vapors were less considered because of the ease with which they took place.

*School of Mines, University of Pittsburgh.

In the Belgian process the advantage of the elliptical shape is largely in greater strength, but the practice in the United States is almost entirely the use of the circular cross-section, the reason seeming to be due to the somewhat greater ease in manufacture.

The other matter of which I wish to speak is with regard to the treatment of the retort residuum, or "residue." If the ores treated are low in silver they are rarely treated. Mr. Pierce has spoken of the fact that they will not bear much transportation charges.

I am familiar with the practice at Bartlesville which the author mentioned in his paper. The loss of silver in this burning process is, or was, very high, amounting to more than 25 percent, and many times to as much as 40 percent. This is largely due to the metallic zinc present, which carries off the silver in roasting.

Several years ago I did a great deal of experimental work on the residues from the ores of the Butte and Superior Copper Company, of Butte, Mont. The residues treated came mostly from Collinsville, Okla., but some from Bartlesville and Graselli were also tried. The reason for this work was the very low price that was being received for the material at that time, due to the large amount of carbon present, the excessively fine character of the material and the high silica content, along with, of course, a rather low value in lead or copper. Among the many things that we tried was sintering, which did away with the fineness and the carbon. We found, contrary to expectations, that this material could be burned with a very low silver loss. This was done by burning the material in the beginning at a very low heat, so as to just burn the zinc, and then later raising the heat to a sintering temperature. These experiments were carried on in a small sintering pan working on the Dwight-Lloyd principle, and the heat was kept down by using a very slight vacuum.

Besides these sintering tests, roasting tests, both oxidizing and chloridizing, were run on the material, and it was found easy to obtain low silver losses if the proper precautions were observed.

Pan amalgamation, hyposulphite leaching and cyanidation were tried and uniformly yielded good extractions when proper precautions were observed. However, the costs were high with these processes, and about this time, due to different handling at the zinc smelter, the silver value of the residue was very materially increased and the lead smelters made very much more advantageous contracts. These prices were such that the outlay of capital for new plants for treatment by the above-named processes was not considered advisable. The value of this residue was at all times much higher than the figures mentioned by Mr. Pierce, running at times as high as 45 oz. per ton.

MR. GEORGE A. PAFF:* Assuming that a manufacturer used from 500 to 1000 tons of spelter per year, can he, with the usual improvised equipment, work over his own skimmings and dross with profit, or shall we conclude that this can only be done economically with the more perfect equipment of the regular spelter producer?

THE AUTHOR: The remelting of dross is easy. The distilling is not so easy. It requires the use of a somewhat difficult process. Remelting is quite simple and quite profitable, that is, people make money by doing it. The treatment of skimmings is a different thing. It has to be reduced in a furnace.

These matters are easily worked out if there is a large enough tonnage. Most plants have not enough. If a large tonnage can be developed it would pay to work them. The smallest tonnage it would probably pay to work would be 10 tons of material per day.

Concerning the use of salt, I hesitated to bring this matter up because it is a somewhat mooted question. The use of salt dates back only about seven or eight years. It appears to act as a sort of sedative in the retort. It seems to quiet down a furnace so that flames coming from the condenser have a less wild appearance, and the furnace seems to work more regularly. It does assist in the crusting up at the neck when the condenser is put in the mouth of the retort. The amount of salt used varies. Some plants use 4 lb. to the ton and some as much as 12 to 15 lb. It is largely employed and seems to work well.

Mr. W. R. Ingalls in his contributed discussion mentions the classification of furnaces made by me.

When I wrote my paper, I did not go into the exact number of retorts in the various kinds of furnaces, but I knew, in a general way, that those in the recuperative furnaces at Palmerton and the Overpelt furnaces at Blende, and a few coal-fired furnaces made a very small percentage of the total number.

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*Superintendent, Wire Dept., Jones & Laughlin Steel Company, Woodlawn, Pa.

This afternoon I made a tabulation from Mr. Ingalls' report in the Engineering and Mining Journal. There were at the close of last year 155 000 retorts in the United States. Each one of these is good for possibly three and one-half or four tons of spelter a year. Our smelting capacity is, therefore, about 600 000 tons a year at the present time. Of that total the retorts in natural gas furnaces are nearly 102 000, or 65 percent. There are two natural gas plants which I have heard are to have gas producers, and thus be what are called Hegeler furnaces. This would take off 14 000 retorts, or about 9 percent. Disregarding these, the Hegeler furnaces have about 26 000 retorts, or 17 percent. The regenerative furnaces have about 21 000, or 13 percent. The recuperative furnaces, the Overpelt and the Belgian have a total of about 6500 retorts, that is, only about 4 percent of the total. They could stop operating now and the country would never know it. For that reason, and also as a general proposition, these furnaces are not particularly practicable for large manufacturing plants, they are not very important. We are manufacturing spelter at a greater rate now than ever before. A plant with a capacity to treat 200 or 300 tons of ore is quite a business. There are two or three plants now that will handle more than 200 tons a day and a great many that handle 100 tons or more.

CORRESPONDENCE

MR. W. R. INGALLS:* It affords me much pleasure to make a few remarks respecting Mr. Pierce's interesting paper. I have an especial interest in doing this for the Engineers' Society of Western Pennsylvania, in view of the fact that I pointed out, about sixteen years ago, the suitability of the vicinity of Pittsburgh as a zinc smelting center. At that time I spent a good deal of time in the region, studying local conditions in behalf of a client who was considering the erection of a smelting works there upon my recommendation. Certain reasons, which had nothing to do with either the geography or industrial conditions of the district, led to the abandonment of this plan, which never passed beyond the preliminary stage. It was but natural that I should view with satisfaction the confirmation of my opinion when the Langeloth plant, and then the Donora plant were built about fifteen years later.

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*Editor, Engineering and Mining Journal, New York.

The paper of Mr. Pierce is a very good presentation of the elements of an American zinc smelting works of the present time, and the operations that are performed in it. However, it is difficult, as Mr. Pierce remarks, to give an adequate view of this subject within the limits of a brief paper. What I shall add to his paper will be explanatory rather than critical, although I shall have to begin by taking a few exceptions to certain of his generalizations.

Thus, I do not agree with him that there is any need for inquiry as to why the zinc business has not been more generally exploited. In fact, the zinc smelting business has been an easy one for people to go into. That very thing has prevented organization and concentration. In the great period of industrial consolidations, fifteen to twenty years ago, attention was directed to the zinc smelting business, efforts were made toward gathering most of the smelters together in a "trust," and some small consolidations were actually made. However, as fast as anybody was bought out, he began promptly to build a new plant with the money that he received, there being no natural conditions that could give any big company a strong hold on the business. Would-be organizers of a "trust" found, therefore, that they were confronted by an endless-chain problem, and gave it up. Indeed, the zinc smelting industry of the United States, almost continuously from its inception up to the time of the outbreak of the great war, was chronically overbuilt. It has been historically an industry of cut-throat competition, small smelting margin trials and tribulations; and the galvanizing consumers of Pittsburgh and vicinity were wise in not going into it. On the average they were able to buy their spelter more cheaply than they could make it.

A feature of the zinc industry to which attention cannot be drawn too emphatically, is that the present era of phenominally high prices is due solely to conditions produced by the war, and may not reasonably be expected to hold, quite irrespective of continuance of the war. In other words, the preposterous rise in spelter price has been due to shortage of smelting capacity, not to zinc ore supply, and the correction of existing conditions is merely a matter of providing additional smelting capacity, which, in fact, is being done very rapidly.

The indications of the profit in zinc smelting at the present time, the cost of smelting, etc., that Mr. Pierce has given, should be construed in the light of the remarks that I have just made. It should be noted, also, that Mr. Pierce is making a generalization in order to give his hearers an idea of what he is talking about. You should not, therefore, hastily make the deduction that an average cost of smelting a ton of a zinc ore is $15. In fact, the cost of zinc smelting, the extraction of metal, and other economic factors of the art vary more in this than in any other branch of metallurgy of which I know, and in giving serious consideration to such figures, there must be attention to explanations, qualifications, and correlative factors that will obtain full appreciation only among experts.

Turning to the more technical part of Mr. Pierce's paper, in describing the retorts he mentions that their diameter is limited for the reason that if they were too large the central portion of the charge would not be sufficiently heated, which would be fatal. This is correct, but without increasing the width of the retort, its height may be increased, and its capacity thereby increased without calling for a penetration of heat greater than is necessary in the ordinary 8-inch cylindrical retort. This leads to a consideration of another physical factor that Mr. Pierce has not mentioned, namely, the ability of the gas and vapor developed in the charge to get out of it. A very low column of fine ore checks the passage of gas and vapor through it, and the finer the ore the lower the column. In Upper Silesia, where the ore was formerly calamine to the major extent, and capable of distillation in relatively coarse condition, muffles 2-feet in height used to be employed. When blende became the predominant ore, and had to be distilled in fine condition, because it had to be roasted in fine condition—if for no other reason,--the Silesian smelters had to change to the Rhenish retorts, which are only 10 or 12 inches high.

American smelters are even now experiencing a similar problem in the treatment of the excessively fine flotation concentrates in the standard 8-inch cylindrical retorts. The gas and vapor generated in the charge may be unable to get out freely, and being penned in may acquire such pressure that it will eventually blow out explosively, throwing out charge and everything.

I do not agree with Mr. Pierce that retorts of oval cross-section may not be made as easily as those of circular cross-section. Among the zinc smelters of Europe the oval retorts are the common thing, the circular the uncommon. But, as I pointed out in the previous paragraph, there are highly important considerations other than those of manufacture.

The statement of Mr. Pierce that the proximity of the condenser to the retort keeps it hot enough to prevent the sudden cooling of the zinc vapor, opens the way to some interesting considerations. I should say, however, that it is not merely a question of the heat that the condenser gets from the retort, but also of the heat radiated from the front of the furnace. Thus, in the Rhenish furnace where the retorts are inclosed within anterior compartments, the temperature of the condensers is regulated by opening and shutting the doors in front. Now, the radiation from the front of a distilling furnace used to be exceedingly deplored. Not only did it make the front of the furnace very uncomfortable for the men, but there was also a terrific loss of heat units. We figured that we could improve the thermal efficiency of the furnace by doubling it, i. e., putting two single furnaces back to back, by increasing the thickness of the end walls and of the roof arch, but with respect to the front of the furnace nothing could be done. It was with a great feeling of relief, therefore, that a few years ago we read the results of a study by a distinguished German engineer, which showed, among other things, that the heat radiating from the front of the furnace was necessary to keep the condensers at the right temperature. This was especially a relief to me, for at about that time I was doing some experimental work with electric furnaces on a small scale, and found it necessary to heat the condenser, actually to put a grate fire under it, which, of course, was contrary to all precedent, but nevertheless the fact remained that it had to be done. In this connection I may digress sufficiently to add that later in operating larger electric furnaces, smelting 2000 to 4000 pounds of ore per day, it was found that the heat carried into the condenser by the gas and vapor from the furnace, was sufficient to keep the condenser at proper temperature, regulation being accomplished by varying the thickness of the covering. Reverting to the condensers of the ordinary zinc distilling furnace, one of the marvellous things of metallurgy to me is the ability to cause gas and vapor coming from a retort, wherein the interior temperature is 1100 to 1200 deg. Cent., to reduce its temperature to 550 deg. Cent., and accomplish so high a degree of condensation within a tapering tube only 18 inches long.

In describing the apparatus for making retorts by the hydraulic system, Mr. Pierce has omitted mention of the hammering machine. Indeed, some American smelters have omitted that important machine from their equipment. This system of making retorts was developed in Europe. American smelters obtained their first presses from Europe and copied the European method of manufacture. In that method, the sausage of clay coming from the pug mill is transferred to the hammering machine whereby it is beaten into blocks which are put into the press. The purpose of this is to make the mass in the press as dense as possible. Otherwise, the trapping of air is likely to cause blisters on the retort, or too much porosity, both of which are highly undesirable features.

The rooms for drying the retorts are seldom as well designed as they ought to be. We shall, no doubt, some day witness among our zinc smelters a much better control of air circulation, temperature and moisture, with the assistance of not only thermometers, but also anemometers, and hygrometers, than we do anywhere at the present time. American smelters do, indeed, use retorts of only six to eight weeks' seasoning, even less in emergencies, but it is better to let them season for a much longer time.

Mr. Pierce's classification of furnaces is intended to summarize certain types that are used in the United States, rather than being offered with the idea of presenting a perfect classification. He should have mentioned the counter-current recuperative furnaces that are used at Palmerton, Pa., and the Overpelt-Rhenish furnaces at Pueblo, Colo. The elevation of the floor of the furnace house is not a necessity of the regenerative or recuperative furnace, for there are many horrible examples of the subterranean construction of the inferior part of the furnace among the older smelters of Europe. The elevated furnace floor was introduced, in the first place, as a measure to improve both working and sanitary conditions. The first example of this construction in the United States was the works at Collinsville, Ill., which had, and has, nothing but old-fashioned Belgian coal-fired furnaces. Whether this ante-dated similar construction in Europe, or not, I do not know, but I think it did.

Blende is nowadays the main source of zinc, as Mr. Pierce correctly says, but the proportion of calamine that comes to the smelters is still surprisingly large. Indeed, it is a fault of a good many of our American smelting works that they do not possess sufficient roasting capacity, which compels them to rely too much on calamine supply and at certain times within recent years has reduced the smelting margin on that kind of ore to a very unsatisfactory figure. Another factor in this was the failing supply of natural gas in Kansas and Oklahoma, and the neglect of the smelters of that region to provide themselves with any type of roasting furnace that was fairly economical of fuel. The roasting furnaces in common use in that region are great fuel wasters, and the smelter who was short of gas supply was, therefore, disposed to buy calamine ore that did not have to be roasted.

The matter of treating flotation concentrates is one that has already exercised the zinc smelters, but is going to do so more and more. There are troublesome problems in connection with this of a nature similar to one that I have mentioned when speaking about the dimensions of retorts. Heretofore, the ore that has come from the flotation mills has been only partially concentrated in that way. A large part of it has been jig and table products, as in former times. However, the day is coming when all the ore from certain important zinc producing mines will be flotation concentrates. As that day draws near, the troubles of the zinc smelter will really begin.

Mr. Pierce's statement that zinc ores containing 25 to 33 percent sulphur if set on fire will burn of themselves under proper conditions until the sulphur is reduced to 6 or 7 percent, needs a good deal of qualification, I think. Lump blende may be ignited in stalls, just as is done in the case of pyrites burning, and for about twenty-four hours will burn actively, in the next twenty-four hours with rapidly increasing feebleness, and in the third twenty-four hours the burning usually ceases. The finer the ore, and the more perfectly heat be conserved, the longer and more complete will be the autogenous burning of blende. In Gerstenhofer furnaces blende used to be burned down to about 5 percent sulphur without the use of any extraneous fuel, but those furnaces, which were built in batteries, were very good from the standpoint of heat conservation. It is my firm conviction that with a suitably designed furnace, i. e., one with proper thickness of walls, control of air supply, and adjustment for heat transference—could be operated so as to cause blende to burn itself down to as low as 1 percent sulphur. However, I have no knowledge of this having been done as yet.

Further on in his paper, Mr. Pierce refers to the temperature of the distillation furnace as being about 1100 deg. Cent. at noon, and at about 1300 deg. Cent. at 2:00 P. M., daily. It should be explained that he is here referring to the temperature of the combustion chamber of the furnace, i. e., the space outside of the retort. The temperature inside of the retort is usually about 100 to 200 deg. less, the relative relation between the temperature outside and inside changing (diminishing) as the distillation proceeds.

The matter of density of charge is one with regard to which there is considerable difference of practice, which is, to a large extent, influenced by the habits of the smelters. The smelters of a certain district become accustomed to charging their retorts in a certain way, and are averse to learning a different way, although metallurigically it may be a superior way. The same company operating works in several districts often finds itself unable to overcome this inertia on the part of its smelters (furnacemen). The introduction of the charge in the form of briquettes is not a matter that is peculiar to any type of furnace, nor is it a recent innovation. The first idea of charging in that way was described many years ago—twenty-five or thirty, perhaps more—and trials of it have been made at many places in Europe, but this practice never became general or steady anywhere.

The residue drawn from the retorts at the conclusion of the distillation still contains several percent of zinc, besides a large excess of unconsumed carbon. It has lately been found that by setting this residue on fire, in heaps, it sinters, and besides permits the recovery of an additional quantity of zinc which is burned off as oxide and may be collected. Reflection about this supplementary process may develop some interesting ideas. However, I fear that I have already discussed Mr. Pierce's interesting paper to excessive length. Indeed, the points touched upon by Mr. Pierce lead into about all the corners of the field of the metallurgy of zinc.

MR. ROBERT LINTON:* I would like to ask Mr. Pierce if there are any new methods for treatment of base zinc-lead ores frequently met with in Western mines and usually designated as "Black Jack." I recall that in a silver-lead mine in Utah that I had charge of several years ago we had a considerable tonnage of such ores. They carried on an average 8 percent lead, 15 percent zinc and 5 to 10 oz. silver. On account of the high zinc contents it was not profitable to ship this ore to the lead smelters, and the zinc contents were of course much too low for the zinc smelters. It was a very hard ore, heavy, dense and fine grained with the constituent sulphides very intimately mixed, if not actually combined to a certain extent.

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*Mining Engineer, Pittsburgh.

I made a number of concentration tests on this ore, hoping to be able to make a separation of the lead and zinc so that both products could be marketed at a profit. Wet concentration did not yield satisfactory results. The tests, which were checked by a ten-ton mill run in the testing plant of the General Engineering Company, gave a product containing about 30 percent lead and 10 to 12 percent zinc, but recovery so low that the net smelter returns from the concentrates produced from a ton of ore were less than the returns from a ton of the crude ore. Roasting and magnetic tests showed more satisfactory results, but in that locality fuel was so expensive, that the application of these processes was not feasible. Flotation had at that time not come into the general use that it enjoys today and no attempt was made to apply it.

I have found similar ores in other parts of the west, and some that are more complex, carrying antimony, bismuth and other constituents. I would be very much interested to know what Mr. Pierce can tell us of methods of reduction of such ores.

MR. JAMES O. HANDY:* The thanks of the Society are due to Mr. Pierce for presenting a paper containing so much interesting and valuable information concerning an industry of great importance, and one which is likely to receive more and more attention from engineers who will strive to simplify the processes and reduce the cost by larger scale production. It will be their hope and aim to eliminate the multitude of small retorts and the intermittent operation of the process as a whole.

In the meantime, much attention will be given to the reduction to the lowest point of the zinc loss in smelting and to recovery of the zinc from fumes, broken retorts and zinc ashes.

It has been estimated that at the average zinc plant, the daily zinc loss amounts to 10 percent and that this loss could be roughly stated as follows:

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*Director of Laboratories, Pittsburgh Testing Laboratory, Pittsburgh.

Daily production,	66 tons spelter.
Daily loss of zinc,	6 tons spelter.
Loss in zinc ashes, 60 tons containing 4% zinc,	2.4 tons spelter.
Broken zinc retorts, 6 tons containing 10% zinc,	0.6 tons spelter.
Zinc vapor escaping,	3.0 tons spelter.

I would be glad to have Mr. Pierce state his opinion as to the average loss and the loss distribution on the above basis.

It would be of interest also to know where the different processes mentioned in his manuscript for recovery of zinc from zinc ash are in use.

Mr. W. McA. Johnson: Mr. Pierce, as former Chief Engineer of a large zinc company, is thoroughly conversant with the facts and figures of the zinc business, and your Society is to be congratulated on having him present this paper which gives, in proper and precise form, such facts and such figures as are needed for an understanding of the practical metallurgy of zinc considered in an intense aspect.

I beg leave to submit certain comments emphasizing various commercial points:

The question of ore supply has been greatly changed by the successful application, in the United States, of the flotation process by the Butte and Superior Company in the year 1913. From it such future developments may be expected in increasing measure, as the wonderful developments in the past two years would seem to indicate. At present there is restriction of this process, due to the unfortunate uncertainty about the validity of the patents. This case has now the distinction of going before the Supreme Court of the United States, where it will be decided on broad principles of equity, looking at the substance of the case, and with recourse to the general principle of equity—that where there has been a substantial wrong there can be found a substantial remedy. When this is once definitely settled, the flotation process will release enormous tonnages of zinc concentrates from numerous mines of small size and several mines of large size in the great country, which in the zinc business, we call the West. The influence of this process on the future metallurgy of zinc cannot be underestimated.

We may also comment upon the entrance of the Anaconda Copper Co., which is reported to be building a plant to produce electrolytic spelter with a yearly capacity of 35 000 tons of nearly chemical pure spelter. Several very strong concerns, such as the proposition at Keokuk for electrolytic spelter, in which it is commonly reported that the Stone and Webster interests are concerned, and the plant of the Bully Hill Company are engaging in serious, large scale electrolytic work. The Bully Hill Company is controlled by the General Electric Company.

As to electric zinc smelting, about which your Secretary has asked me to comment, I might state that the process was developed on a one ton basis at Hartford to a certain definite stage, and I turned over the commercial development to other hands. These people have made several sets of drawings of a careful and exact nature, but they have built no electric zinc furnace. I am acting with them in a purely advisory capacity. I am also acting as consulting engineer for a concern that makes strictly high grade spelter of especially fine physical and chemical properties by a process somewhat similar to that once used at the Bertha plant.

There are many projected developments in the metallurgy of zinc which have reached a stage something beyond an embryonic one, but it is, perhaps, premature to talk about these at the present time.

Concluding, let me compliment Mr. Pierce on his most excellent monograph, which might be well expanded into a book for practical zinc men.

THE AUTHOR:* In reviewing the discussions and comments on my paper I am very much pleased with the kind spirit shown and am certainly obliged for the attention that has been called to omissions which in some cases are very important.

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*Author's closure.

Mr. Ingall's views of the exploiting of the spelter business agree substantially with those I tried to set forth perhaps not very clearly. The fact remains that the large consumers of spelter and others were caught shortly after the great war started and most of them stand today fastened with bait and hook. It seems to me quite an interesting question, and well worth comment.

With the producing capacity of the country practically doubled spelter continues to rise in price and this is contrary to the opinion of almost all who are in close touch with the situation. All seem to agree that production is on a tremendous scale and the price should drop, but it continues to rise. Some day it will certainly drop and it is perhaps a little safer to be on that side of the question.

As to the cost of smelting zinc ore, $15 per ton was a conservative figure. I know of plants where the cost has been as low as $10 per ton, but as Mr. Ingalls says, it is very variable. It depends on the location of and conditions at the smelter. If it is higher than $15 in normal times something is wrong at the plant and should be corrected.

The comments concerning retorts are well taken and the omission of mention of the character of the one as affecting the diameter and shape of the retort was a serious one on my part. American practice favors round retorts because it is possible to make more satisfactory round retorts than those of oval cross-section. The reason for this may be lack of skill on the part of our workmen, but whatever it is the round retort prevails.

In the manufacture of retorts the clay is not generally passed through the hammering machine. This has been superceded by the first manufacturers of that machine by what is styled the "Ballot Kneader," which is a large vertical pug mill. In this country the same practice exists, but the machines are horizontal pug mills. It is the general opinon that the retorts thus made are quite as good as those with the hammering or "Schlag" machine.

Mr. Ingalls had for review a preliminary draft of my paper and in that form rather more stress was laid on the drying rooms and the control of the operation of drying the retorts. I regard his comments on this as most important.

In my discussion at the meeting I have already made some answer to Mr. Ingall's comments on the classification of furnaces so called. I did not intend to be understood as proposing anything but a grouping of the furnaces in common use.

It is my understanding that in the early days at Friedensville, Pa., the zinc blende from that mine was roasted in heaps down to a sulphur content of 6 percent. This roasted ore was used for the manufacture of both spelter and zinc oxide. The same practice was carried on elsewhere in this country.

I am quite aware of the fact that briquetting the retort charge is not new. In fact I have a copy of an ancient patent on the process with a wonderful illustration, but it was not worked out successfully at that time and has not been used up to the present. The reference I made was to the U. S. patent No. 1 137 835, of Mr. G. S. Brooks of the Mineral Point Zinc Co., Depue, Ill., where the use of briquettes has been worked up to a very successful stage. To be sure this scheme may be worked on any furnace, but it has been developed on the Siemens furnaces and because of the character of the manouvre on such furnaces, particularly the disposition of the blue powder in the top retorts, it would seem to be the better furnace for the briquettes.

With the briquettes a more porous charge is effected and fine ore may be used without stoppage of the gases and fumes during the distillation. This is another advantage of the use of briquettes not noted in my paper, and may have an important bearing on the use of flotation concentrates.

Referring to Mr. Linton's questions as to the treatment of "Black Jack" or similar ores, I think the process of leaching and electrolytic zinc precipitation probably holds out the most promise. So many excellent papers on this subject have appeared of late I can only refer to them in this general way as covering the situation quite satisfactorily.

In answer to Mr. Handy's question as to the losses of zinc in smelting, the actual figures given by him are a little low for average conditions. His reference to zinc ashes should more properly read furnace residues and a more average percentage of zinc content would be 6 percent. The residues will be in weight about 65 percent of the ore charged. The zinc lost in residues will be about 8 percent of the metal in the ore. The metal loss in old retorts and condensers is about 2 percent. The loss in fume is commonly set at 3 percent. The loss in roasting and handling is about 1½ percent. The total losses about 15 percent or a little less. A very good average plant recovery is put at 85 percent.

Zinc residues are supposedly treated at all plants of the American Metal Co. and its subsidiaries. They control patents on certain processes for residue treatment, already referred to. This would include Bartlesville and Collinsville, Oklahoma and Langloth, Penna.

ELECTRIC SERVICE PROBLEMS AND POSSIBILITIES

By P. JUNKERSFELD*

Every branch of human endeavor toward advancement has its problems and its possibilities. Some of these affect or interest comparatively few people. Others affect the comfort and convenience of very large numbers of people. This latter is especially true of public utilities, such as transportation, gas, telephone, electricity and others.

The rendering of electric service to large numbers of people is the newest of these different utilities and for that reason, as well as because of its rather complicated nature, is, perhaps, not so well understood as most of the other utilities.

INCREASE IN DEMAND FOR SERVICE

The first electric generating plant put into commercial service for supplying the public was a very small plant at Appleton, Wisconsin, in April, 1882. This was followed very soon after by the famous Pearl Street Station in New York City which was put into commercial service about September, 1882. From these small beginnings the business has developed so that according to the United States census of 1912 the capital invested in the United States in the business of supplying electric service was upwards of two billion dollars. Today it is about three billion dollars. While the principles underlying electric service are similar there are often local conditions that make the solution of some of the problems in one locality different from another equally good solution for another locality. In order, therefore, to illustrate with more definiteness and clearness the problems and possibilities in the rendering of electric service, references will be made to its development in Chicago, with which the writer is most familiar.

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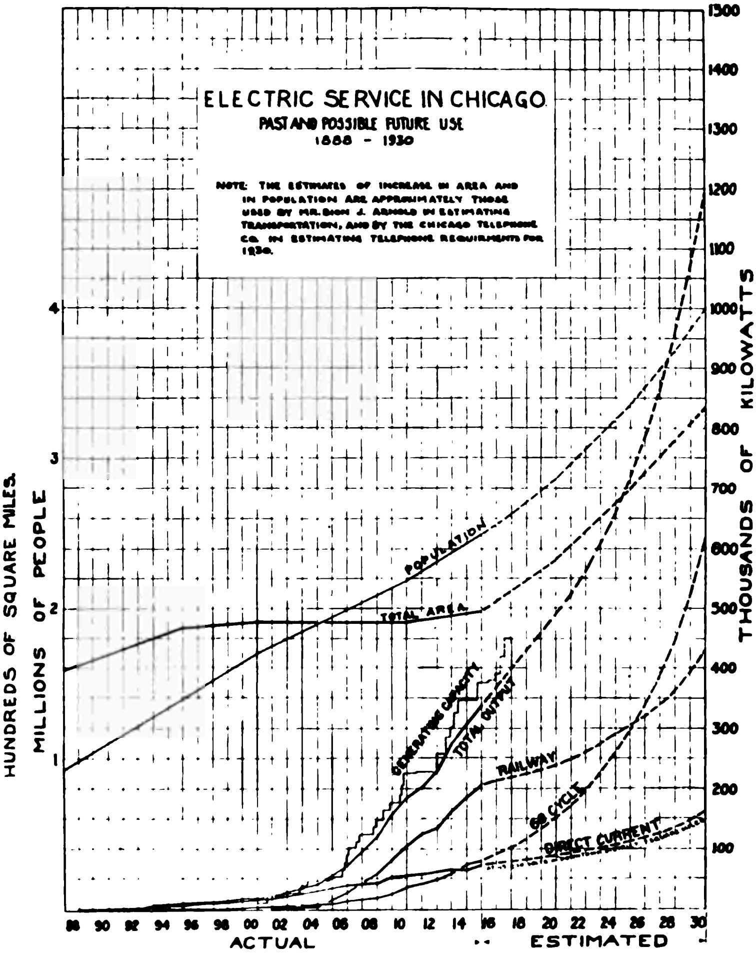
*Assistant to Vice President, Commonwealth Edison Company, Chicago

In Fig. 1 is shown graphically the increase in maximum output each year from 1888 to 1916, also an estimate of such output until 1930. In 1888 the output was so small that it can hardly be read on the chart, but after several years of slow but steady growth it began to increase at such a rapid rate that the maximum output in one hour in November, 1915, averaged 337 900 k. w. If the estimates are correct, the maximum output will, in 1930 ex-



ELECTRIC SERVICE IN CHICAGO
PAST AND POSSIBLE FUTURE USE
1888 - 1930

NOTE: THE ESTIMATES OF INCREASE IN AREA AND IN POPULATION ARE APPROXIMATELY THOSE USED BY MR. BION J. ARNOLD IN ESTIMATING TRANSPORTATION, AND BY THE CHICAGO TELEPHONE CO. IN ESTIMATING TELEPHONE REQUIREMENTS FOR 1930.

Fig. 1

ceed 1 000 000 k. w. The estimates for future increases are based upon the assumption that the present population, according to the latest City school census, of 2 530 000 will reach 4 000 000 by 1930. This is the figure used by such authorities as Mr. Bion J. Arnold in his calculations for traction requirements and by the engineers of the Chicago Telephone Company in their calculations for telephone requirements. It is also assumed that the area of the City will be increased as indicated in the "Total area" curve in Fig. 1 and as shown graphically in Fig. 2, the latter being a map showing among other things the present boundaries of Chicago and the estimated limits in 1930.

RELATIVE DENSITY OF DEMAND

One of the most important factors that affect the cost of rendering electric service in the density of electric service, that is, the quantity of electricity used in a given area. In order to illustrate relative density, the City of Chicago has been divided into three major zones and each of these three zones divided into two parts unequal in area, but equal in total quantity of electricity used. This map also shows the location of the present and future principal generating stations.

The maximum density of the entire city is in the Loop District where the average is 80 000 k. w. per square mile. The minimum density is in the western part of the southern zone and is only 68 k. w. per square mile. The relative density in the six sections of the City is shown by the degree of shading in Fig. 2 and also in Table No. 1.

TABLE NO. 1. DENSITY OF DEMAND PER SQUARE MILE—1915

Northern Zone		
East Portion Averages	2433	k. w.
West " "	426	"
Central Zone		
East Portion Averages	3023	k. w.
West " "	836	"
Southern Zone		
East Portion Averages	127	k. w.
West " "	68	"

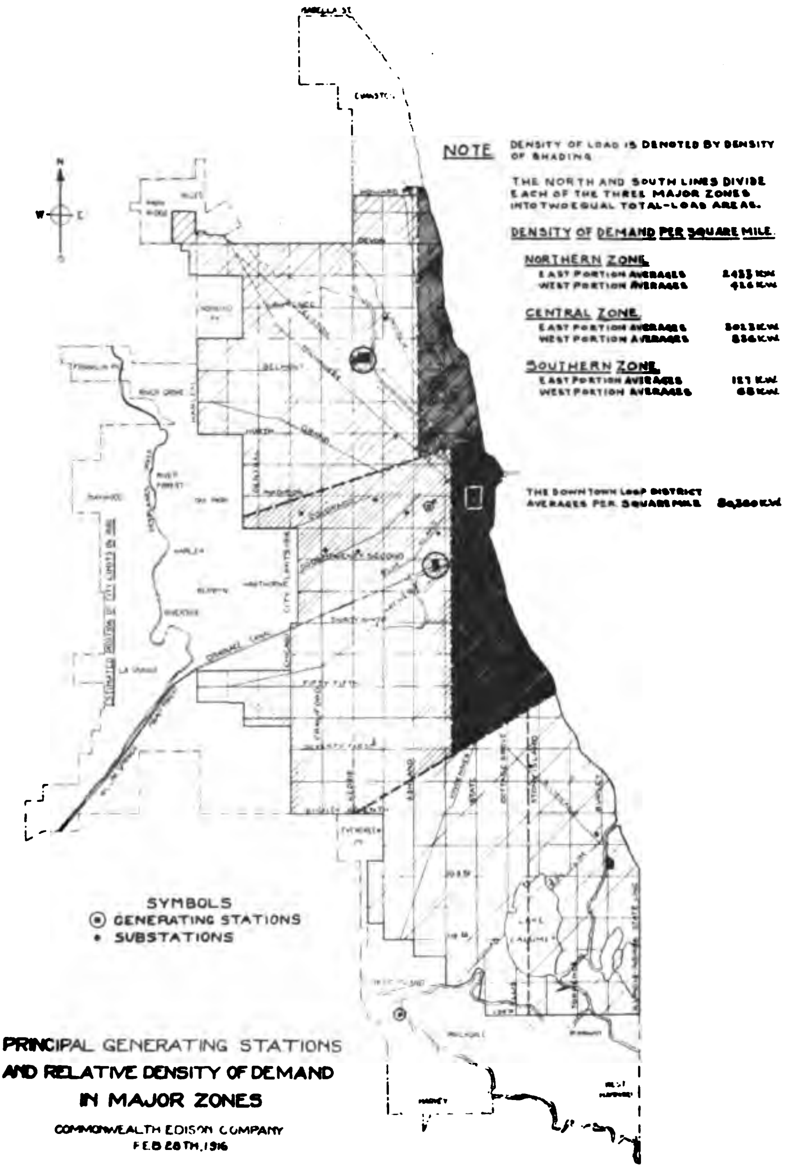

NOTE
DENSITY OF LOAD IS DENOTED BY DENSITY OF SHADING
THE NORTH AND SOUTH LINES DIVIDE EACH OF THE THREE MAJOR ZONES INTO TWO EQUAL TOTAL-LOAD AREAS.
DENSITY OF DEMAND PER SQUARE MILE.
NORTHERN ZONE
EAST PORTION AVERAGES 2433 K.W.
WEST PORTION AVERAGES 426 K.W.
CENTRAL ZONE
EAST PORTION AVERAGES 3023 K.W.
WEST PORTION AVERAGES 836 K.W.
SOUTHERN ZONE
EAST PORTION AVERAGES 127 K.W.
WEST PORTION AVERAGES 68 K.W.
THE DOWNTOWN LOOP DISTRICT AVERAGES PER SQUARE MILE 80,300 K.W.
N
W
E
S
HOWARD
DEVON
BELMONT
NORTH
MADISON
DRAINAGE CANAL
CITY LIMITS
SYMBOLS
GENERATING STATIONS
SUBSTATIONS
LAKE CALUMET
PRINCIPAL GENERATING STATIONS
AND RELATIVE DENSITY OF DEMAND
IN MAJOR ZONES
COMMONWEALTH EDISON COMPANY
FEB 28TH, 1916

Fig. 2

GENERATING STATIONS

At this point might be noted the solution to date of the very important problem of providing generating capacity for the future. The Northwest Station is located reasonably central for the entire northern zone, although at the present time it is located some 2 miles westward from the "center of gravity" of the present load in that zone. The future growth must inevitably be toward this generating station, which will make its ultimate location much more central than at present. It is located on 59 acres of ground on the west bank of the Chicago River and about ¾ mile from the Chicago and Northwestern Railway tracks. Adjacent to and on the east side of these tracks is an additional area of 35 acres for storage of cars and coal in bulk. There is also a private right of way 125 feet wide on which is located a privately owned double track electric railroad on an elevated embankment. This railroad is used to bring coal from the Chicago and Northwestern tracks to the station and at present consists of four and one-half miles of single track, including sidings. It has been in operation for four years and was the first electric railroad in Chicago for handling standard cars from a steam railroad. The electric locomotives receive 600 volt, direct current energy from 3rd rail of the underrunning protected type.

The present installation in the Northwest Station consists of two 20 000 k. w. and one 30 000 k. w. steam turbine driven generating units. An additional 30 000 k. w. unit is in process of installation, and two more 35 000 k. w. units have recently been placed under contract for installation in 1917. When these are in service the capacity of the Station will be six units aggregating 170 000 k. w. The area of land is sufficiently large and the condensing water and coal transportation facilities, even in the present state of the art, can be made sufficient for double this aggregate capacity when required in the future.

The Fisk and Quarry Street Stations are likewise located reasonably central to the zone they are designed to supply, and also, at present, within one mile of the center of gravity of the electric load in the entire city. In 1902 this location was nearly 3 miles from the center of gravity of load in the entire city. The selection of this location has, therefore, proved fortunate. The

Fisk Street Station at present has ten steam turbine generating units of 12 000 k. w. each, one of 20 000 k. w. and one of 25 000 k. w., or an aggregate capacity of 165 000 k. w. The corner stone was laid in 1903. This station is very well known in the electrical industry as it was the first large station designed exclusively for steam turbine units.

The original design contemplated 14–5000 k. w. units. The first three original units were rated at 5000 k. w. but the fourth at 7500 k. w. and the fifth at 12 000 k. w. Ten of these 12 000 k. w. units were then installed within a period of six years, including the entire replacement of the first four units, complete with foundations and auxiliaries. The life in service of the first and pioneer, 5000 k. w. unit was 5½ years and the life of the fourth unit was only 3 years. This indicates how quickly electrical equipment may become inadequate in a rapidly growing business and which may necessitate the writing off within a very short time of a large amount of capital. In this instance it was about $1 000 000.

In 1913 and 1914 the Fisk Street Station was further extended by the installation of a 25 000 k. w. and a 20 000 k. w. steam turbine generator. In passing it should be noted, however, that the equivalent boiler room area which originally housed 8 boilers to supply steam to a 5000 k. w. steam turbine unit now houses 4 double boilers supplying steam to a 25 000 k. w. unit. The steam consumption of the orginal three units was about 22 lbs. per k. w. h., while the steam consumption of the latest two units is about 11½ lbs. per k. w. h. In addition the latest double boilers are equipped with economizers and have many other improvements. The use of higher steam temperatures will make possible still better economy in future, but will also necessitate the solution of many additional problems to insure reliability of service and low maintenance costs.

The Quarry Street Station has 6 14 000 k. w. steam turbine generating units of similar design to the 10 12 000 k. w. units in the Fisk Street Station just across the river. In the building of such generating and transmission system for a large city, it is advisable to provide ample reliability. This means avoiding concentration of too large a proportion of total load in any one station or section of a station. It is also necessary to secure the greatest ultimate rather than immediate economy of investment. The first unit in such of the three stations were put into service on the following dates:

Original first unit Fisk street, 5 000 k. w....October 2, 1903
Original first unit Quarry street, 14 000 k. w....October 29, 1908
Original first unit Northwest, 20 000 k. w.......... July 14, 1912

The Fisk Street Station was built in four sections. The first section was begun in 1903 and the last section completed in 1915. The station is today not yet complete, there being room for two more large units.

The Quarry and Northwest Station buildings were each built in two sections. The former is filled up with equipment and the latter will be when the three units on order are in service. This program of piecemeal construction was not always the most economical in each individual part of the whole, but it provided the greatest reliability of service and economy in purchase of real estate and installation of underground transmission system. Locations for generating stations and often for substations and transmission lines must frequently be selected and secured several years before they are used. This means, for a time, unproductive or unused investment, but it is necessary to secure the greatest ultimate economy. The unused portion of underground conduit for instance is about one-half of the total in many rapidly growing cities.

Properly controlled imagination, that valuable asset so frequently undeveloped or lacking even among engineers, has rarely been found consistently adequate in the proper development of electric service for every purpose in a growing community. Such proper development also requires continuity of policy, of thought and of direction loyally supported by a skilled and well balanced organization. This is possible only by affording a reasonable tenure of authority and employment. It is absolutely impossible with such uncertain tenure as would result, for instance, from the success of this or that faction or political party.

ELECTRICAL ENERGY AND ELECTRIC SERVICE

At this point let us consider the distinction between the mere supplying of electrical energy and the rendering of complete electric service. There is a very wide difference in the extent and complication of the two processes, and hence also in the price. The supplying of electrical energy in bulk at a high voltage to railway companies or to larger industrial establishments, is comparatively a simple matter. It means the delivery of a raw product or at best a partially finished product not yet in usable form. The only investment charges or maintenance expense required are those for the generating station and high tension transmission lines. The only operating expenses are those for the generating station, of which the cost of coal is about 75 percent. After adding the investment charges at, say, a 40 percent annual load factor and the small proportion of general expense usually incurred, the cost of coal is still on the order of 33 percent of the total cost of supplying high tension electrical energy in bulk.

RELATIVE COAL COSTS

Contrast this with complete retail electric service to homes in which the cost of coal is usually less than 4 percent. The cost of the raw product coal has here become a very small proportion. The very large proportion of the cost to render electric service to homes is that due to very heavy investment charges and to very expensive service.

Twenty-five years ago when the possible radius of distribution was a matter of only a mile or two, a non-condensing plant was usually operated near the center of the area served. At that time the cost of coal was often the largest item, even in electric service to homes. The householders taking electric service have, therefore, been very greatly benefited by the use of electrical energy for a great diversity of purposes. The constantly increasing field for electricity and developments in electric transmission and conversion have made possible the concentration of production at distant points where condensing water and coal receiving facilities were available. However, even after that was possible the efficiency of power generation has been very much improvd. For instance, the cost of coal per k. w. h. or unit of energy has been greatly reduced in the last twelve years.

In 1903 the average coal consumption for the entire year from all stations of the electric utility in Chicago was about 7 lbs. per k. w. h. This was Illinois coal with about 10 000 B. t. u. per

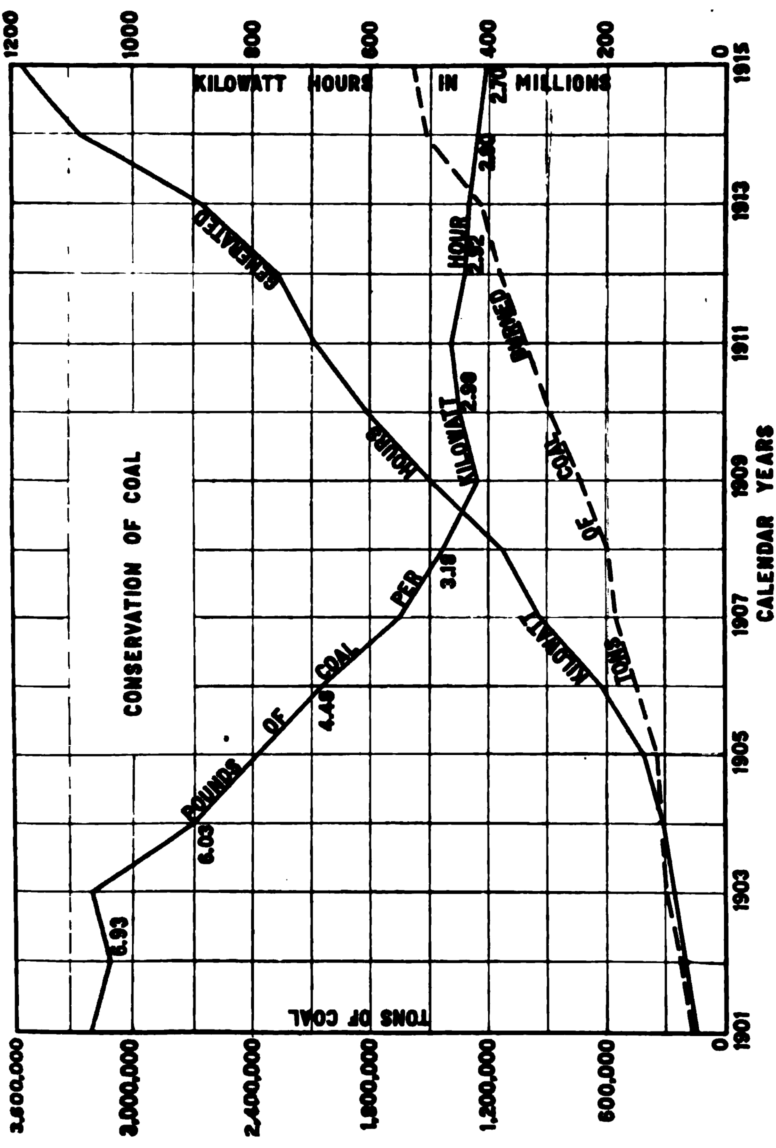

CONSERVATION OF COAL
KILOWATT HOURS IN MILLIONS
TONS OF COAL
CALENDAR YEARS
1901
1903
1905
1907
1909
1911
1913
1915
0
200
400
600
800
1000
1200
0
600,000
1,200,000
1,800,000
2,400,000
3,000,000
3,600,000
GENERATED KILOWATT HOURS
POUNDS OF COAL PER KILOWATT HOUR
TONS OF COAL BURNED
6.93
6.03
4.48
3.16
2.90
2.92
2.90
2.70

Fig. 3

pound. At present the average consumption at all stations is about 2.7 lbs. per k. w. h. The coal consumption of the latest units averages about 1.95 lbs. per k. w. h.

In 1903 about 75 percent of the annual output was generated by compound reciprocating engines, none of which were larger than 3500 k. w. but were among the most economical generating units in the country at that time. At present about one-half the yearly output is being generated by steam turbine driven units of 20 000 k. w. and larger capacity. One or two new units have been installed each year and these new, larger and more and more economical units are operated the longest possible number of hours consistent with good maintenance. The least economical units or stations are operated only during peak hours, if at all, or held in reserve for emergency.

CONSERVATION OF COAL

During the year 1915 the output was about 1200 million k. w. h. and required 1 586 000 tons of coal as shown in Fig 3. At the coal consumption per k. w. h. which prevailed in 1903, the total would have been 4 195 000 tons. The saving in coal in 1915 alone was, therefore, 2 609 000 tons. This conservation of coal is due to steam engineering development and to electrical engineering and new business development and enterprise that made possible the purchase of so many new and very economical units in such rapid succession. Low electric power costs are obviously of great benefit to almost every community. Unless water power is available, the cost of fuel is the factor of first importance. After that, the securing of sufficient business at some profit and the skillful physical development of a system are closely interlinked problems, the solution of which must be judiciously coordinated.

RELATIVE INVESTMENT REQUIRED AND EFFECT OF DENSITY OF CUSTOMERS

The high tension transmission system in Chicago, over which 337 900 k. w. was transmitted in November 1915 to 76 substations consists of 725 miles of underground three conductor cables and 12 miles of overhead three conductor lines. This transmission system is shown in Fig 4. The distribution system beyond these substations consists of 2050 miles of single conductor under-

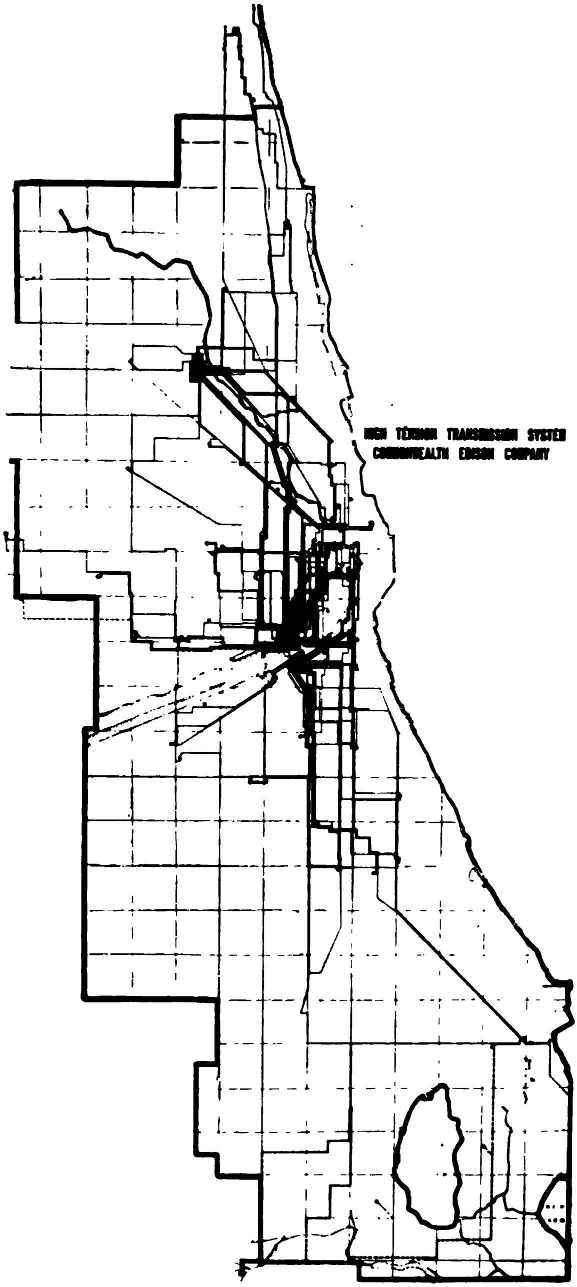

HIGH TENSION TRANSMISSION SYSTEM
COMMONWEALTH EDISON COMPANY

Fig. 4

ground and 7850 miles of single conductor overhead wire. In an area of 7 square miles in the downtown district all conductors are underground. In all the remainder of the city the distribution is partly underground and partly overhead. The feeders or circuits from the substation are carried underground in streets for distances of 1 to 4 miles and then overhead in alleys, as shown in Fig. 5. The primary distribution is 2300–4000 volts, four wire, three phase. Such portions of these circuits as carry no power are single phase, to which a third wire is added when power is added to the load.

In Table 2, column *"A"* shows approximately the relative investment required to supply electrical energy untransformed at a large substation; column *"B"* that to render the same electric service to one of five residence customers in a block; and column *"C"* that to render it to one of 50 residence customers in a block.

TABLE 2. RELATIVE INVESTMENT FOR THREE DIFFERENT CUSTOMERS

	"A"	*"B"*	*"C"*
Generating station	12.3%	12.3%	12.3%
Transmission system	3.2%	3.2%	3.2%
Substations	......	4.4%	4.4%
Distribution to block in which home is located	......	9.3%	9.3%
Distribution within such block	......	58.6%	12.0%
Meters	......	9.0%	9.0%
Lamps	......	3.2%	3.2%
	15.5%	100%	53.4%

If for simplicity of illustration we assume (*A*) that the electric utility has only two classes of customers and (*B*) that the yearly load factor of each customer in the two classes is the same, and (*C*) that the same yearly fixed charge could be applied to the entire investment used for each customer, then the investment charge for the consumer of untransformed energy would be only 15½ percent of that for the residence customer who is one of five customers in a block.

Column *"B"* shows the relative investment costs of the man who is one of only five small residence customers in a block. If there are fifty similar small customers in a block, as in the case of large flat buildings, the total investment charge as shown in column *"C"* is reduced almost one-half.

The reason for this large reduction is, that for mechanical reasons the poles, the primary wires and the secondary wires necessary for five customers to the block, are also sufficient to supply 50 customers to the block. The only additional investment for 50 customers instead of 5 customers in a block, is the larger transformer and the additional number of service drops. If every block in a city or in an area served had 50 or more customers, there would be a considerable reduction also in the items of transmission, or substations, and of distribution to the boundary of the block. The above, together with the table, illustrates the very

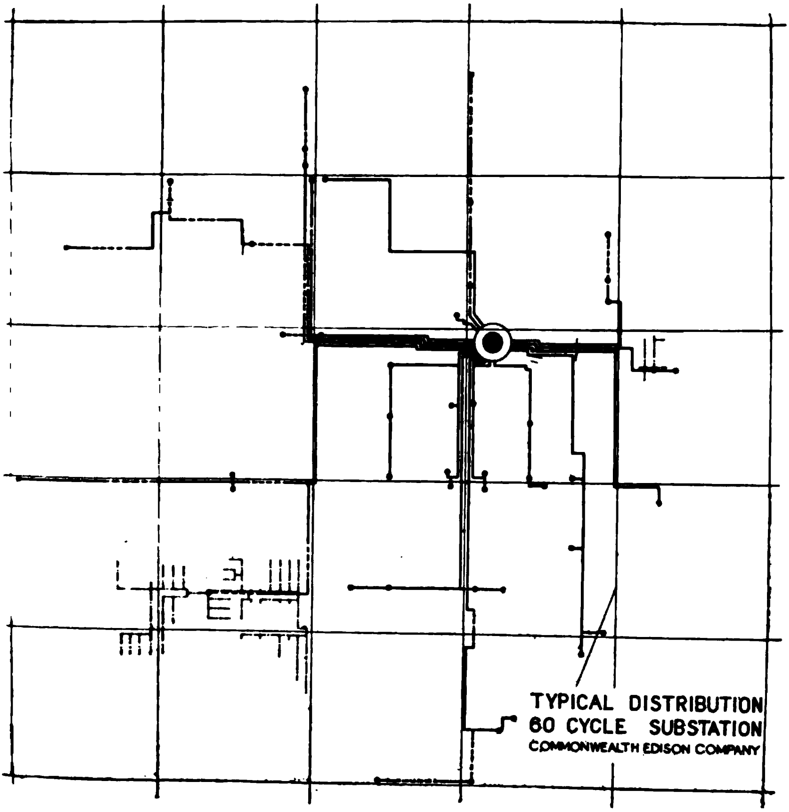


Fig. 5

great influence of density on investment required to render electric service to homes. It also shows that the investment per unit of demand is 6 or 7 times as great for the small customer in column "*B*" as for the large customer in column "*A*." The interest and other fixed charges in this investment must be paid from month to month and from year to year. The interest and other fixed charges go on and on and must be paid when the customer uses the service only five minutes per day as well as when he uses it five hours per day. This is one of the reasons why a minimum bill each month is equitable and fair.

RELATIVE EXPENSES OTHER THAN INVESTMENT

All of the expenses per k. w. h. (other than fixed charges on investment) incurred in supplying electrical energy untransformed in bulk, are only about 6 or 7 percent of those incurred in rendering electric service to a very small customer (5 customers to the block). In the case of untransformed energy in bulk the only large expenses are those in operating and maintaining the generating station and the transmission lines. The cost of reading and maintaining meters and rendering and collecting of bills for such large customers is relatively a very small item.

In the case of the very small customer that we are considering, the operating and maintenance expenses in connection with the substation, complete distribution system, meters and lamps and often certain free repairs for customers are a very large item. The general expense incurred in reading, testing and maintaining meters, rendering and collecting bills and keeping and carrying the account is just as great for the smallest customer as for a moderate size customer. Here then is another reason why a proper minimum bill is necessary to prevent injustice and it therefore is equitable.

The rendering of such general repair and inspection service day and night for convenience of customers as is demanded in rapidly increasing proportions, amounts to a very large sum at the end of the year. There are also heavy seasonal expenses; for example, about 30 percent of all residence customers in Chicago or 82 000 customers moved from one location to another in 1915. Most of them want to be disconnected and reconnected at a specified day and hour. This means an enormous strain on employes as it is impossible to render such service with new people employed for a few days during the rush of May 1st and October 1st. Other work must therefore, be neglected to some extent and all efforts concentrated on this enormously expensive semi-annual waste necessarily incident to moving. Many such customers are a source of annual losses which unfortunately must be made up by the other more thrifty and settled customers.

METERING AND BILLING METHODS

The cost each month of reading the meter, entering on the books, rendering the bill and making the collection, is about 16 cents per bill. This is repeated 12 times a year. This 16 cents is a very large proportion of a bill for electric service that is often $1.00 or less per month. Here is another important problem. If such bills could be rendered quarterly and collected without prohibitive loss the saving would be considerable and of which saving the customers would ultimately receive the benefit.

One great psychological difficulty with present methods is that most residence customers look on electric light bills as monthly transactions because the bills vary from month to month. If a fixed amount could be billed and collected, say quarterly in advance and the excess or deficiency adjusted after reading the meter annually or semi-annually, it would result in a very great saving which would ultimately benefit the customers. While the present type of electric meter is a wonderfully reliable and accurate instrument for the price, there is after 30 years of development still room for revolutionary improvements. The possibilities of simplified methods in metering, billing and collecting and hence of relations with customers are very great and the necessity for such simplification is becoming more urgent year by year.

INCREASING THE OUTPUT

We have been considering two extreme cases, one very large and one very small customer for illustration. The investment cost per k. w. of demand was, you will recall, nearly seven times as great for such residence customer, and all other costs per k. w. h. of use about fifteen times as great for such residence customer as for the street railway. A large proportion of the business of an electric utility, however, lies between these two extremes. It is a very difficult matter to determine accurately the relative cost to supply each of the many different customers under widely varying conditions of service between the two limits considered above. It is, however, necessary to keep the matter of cost constantly in mind because any customers that are served below cost to render service involve a loss that must eventually be borne by the other customers. It is one of the present problems of every electric utility to so conduct its business that the number of customers served below cost shall not become too large and thus prevent an injustice to all other customers.

Even if it were possible, it is, however, not at all necessary, that all customers should afford the same percentage of profit. In a great many instances it is necessary in order to secure additional customers that they be served at a lower margin of profit than is afforded by some existing customers. Every customer added to the utility, if he affords any profit at all, is a source of benefit to all of the other customers, provided always, however, that there should be no discrimination in rates under like conditions of service. Take for example again, the electric railway business in Chicago. During the first two or three years this railway business was served at practically no profit. The demonstration was however, successful and as a result the sale of electrical energy to the railways increased rapidly and soon afforded a reasonable profit. Since then this railway business has made possible the very large and economical power houses and transmission systems from which all of the other customers have since received very large benefits, as demonstrated by the various reductions in rates. In this respect the sale of electrical energy is not essentially different from the sale of the output of a manufacturer who makes a moderate profit on his regular line. In order, however, to run his factory more economically it is advisable for him to take on an additional line and, if possible a line that can be manufactured during the particular season of the year when the demand for his regular product is at a minmum. When first taking on the additional line he is entirely justified in doing so at a low margin of profit or no profit at all, and by so doing increase the quantity of his entire production so much that he is finally able to cut down the margin of profit both on the standard line and on the additional line, thus benefiting both his old and new customers.

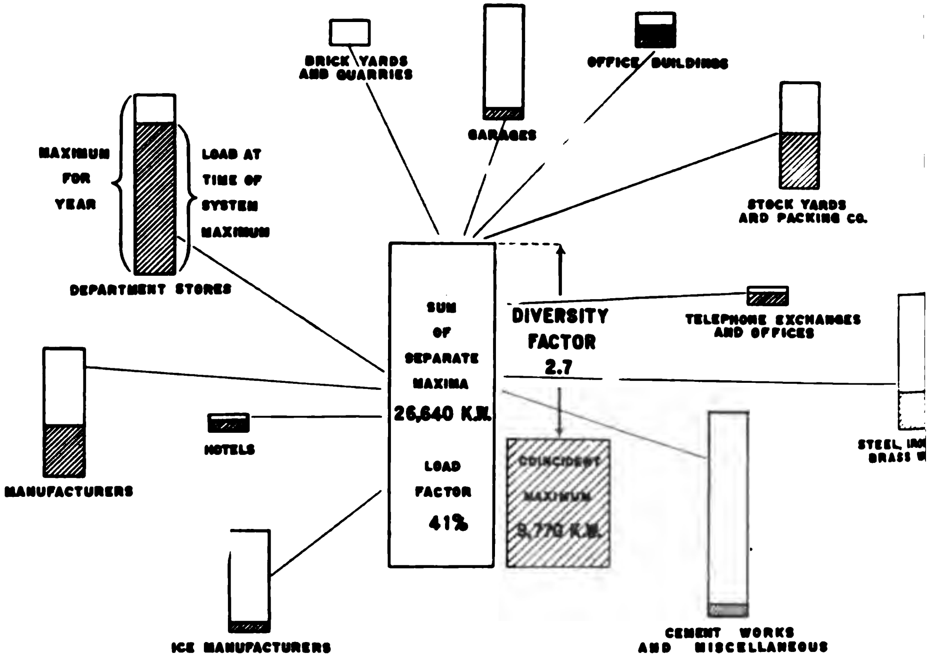
The fixed charges on investment, interest, depreciation and the like, are the largest portion of the cost to serve the majority of users of electric service. The matter of load factor is, therefore, of vital importance, that is, if a dollar invested in the electric utility can be made to work twice as many hours per day the fixed charges are correspondingly reduced. This is what happens if the same equipment can be used to supply one or a set of customers during the early hours of the day and another set of customers during the evening and night hours with no overlapping of the two demands. In most cases this is only partially true. This so-called diversity of demand is a fundamental and important economic reason for massing of production on a large scale. An exhaustive study was made two years ago of the demand of 82 customers which were classed into eleven groups as follows and shown in Fig. 6.

Department Stores
Office Buildings
Hotels
Telephone Exchange and Offices
Garages
Brickyards and Quarries
Steel, Iron and Brass Works
Cement Works
Ice Manufacturers
General Manufacturers
Stockyards and Packing Companies.

The consumption of electricity was automatically printed on a paper tape for each of these 82 customers at the end of each hour by instruments known as Printometers. The hour as well as the amount of the maximum demand of each one of the 82 customers was thus made available.

The sum of the separate maxima was 26 640 k. w. The coincident maximum, however, at the time of the maximum demand (about 5:00 o'clock p. m. in December) on the electric utility was 9770 k. w. This means a diversity factor of 2.7. Some of the 11 groups, such as brick yards, cement works and ice manufacturers made practically no demand at that hour and season. Certain others such as steel, iron and brass works, general manufacturers and the like make their greatest demands about 10:00 o'clock in the morning.

This study of diversity is referred to at length in a paper by Mr. Samuel Insull entitled "Centralization of Energy Supply" and delivered before the finance forum of the New York Y. M. C. A. on April 20th, 1914.


BRICK YARDS AND QUARRIES
GARAGES
OFFICE BUILDINGS
STOCK YARDS AND PACKING CO.
MAXIMUM FOR YEAR
LOAD AT TIME OF SYSTEM MAXIMUM
DEPARTMENT STORES
SUM OF SEPARATE MAXIMA 26,640 K.W.
LOAD FACTOR 41%
DIVERSITY FACTOR 2.7
TELEPHONE EXCHANGES AND OFFICES
STEEL, IRO
BRASS W
COINCIDENT MAXIMUM 9,770 K.W.
MANUFACTURERS
HOTELS
ICE MANUFACTURERS
CEMENT WORKS AND MISCELLANEOUS

DIVERSITY

OF LARGE LIGHT AND POWER CUSTOMERS

Fig. 6

REDUCTION IN COST OF ELECTRICITY FOR LIGHTING

The annual output from 1896 to 1915 inclusive increased from 15 700 000 k. w. h. to 1 198 637 000 k. w. h.—i. e., the output in 1915 was 75 times as great as in 1896. This made possible some material reductions in the average price of electricity for lighting,

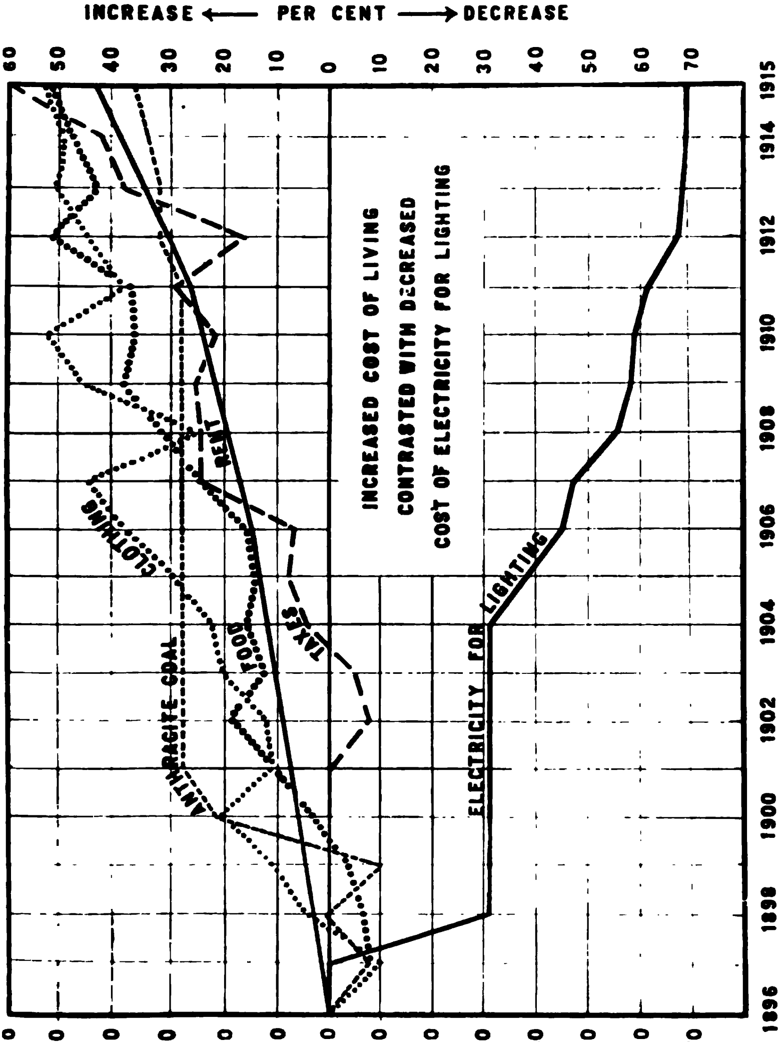

INCREASE ← PER CENT → DECREASE
60
50
40
30
20
10
0
10
20
30
40
50
60
70
1896
1898
1900
1902
1904
1906
1908
1910
1912
1914
1915
INCREASED COST OF LIVING
CONTRASTED WITH DECREASED
COST OF ELECTRICITY FOR LIGHTING
CLOTHING
RENT
FOOD
TAXES
ANTHRACITE COAL
ELECTRICITY FOR LIGHTING

Fig. 7

as shown in Fig. 7. Prior to 1898 the rates were 20c per k. w. h. At that time the so-called Wright Demand System of rates was put into effect for the first time in America. This made it possible for long hour profitable users to automatically earn a better rate than the short hour unprofitable users. This resulted in the rapid increase in the sale of electrical energy for all purposes.

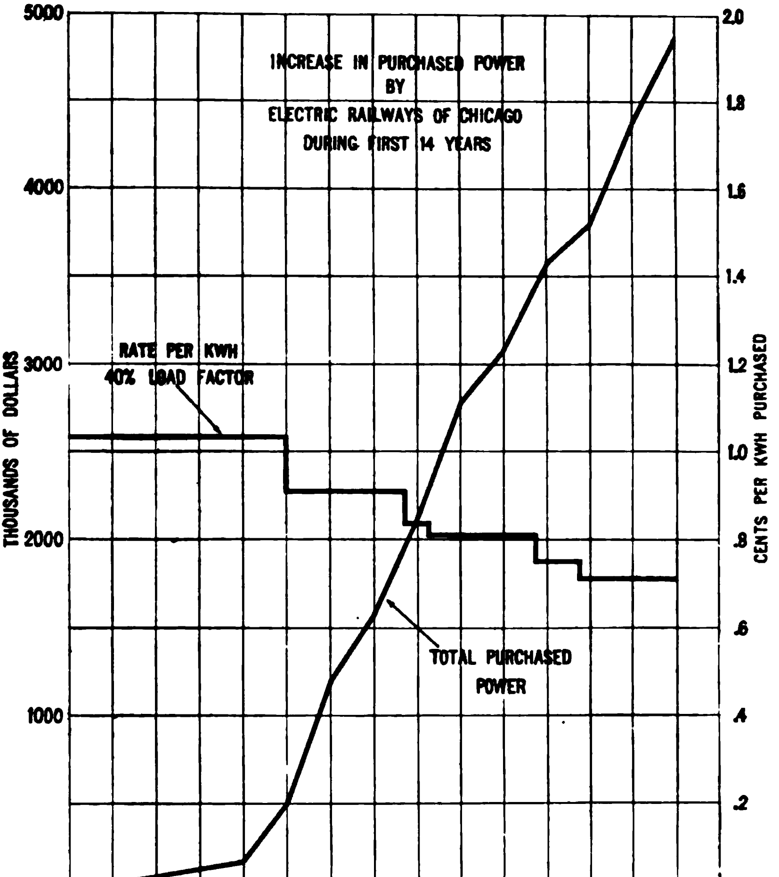


Fig. 8

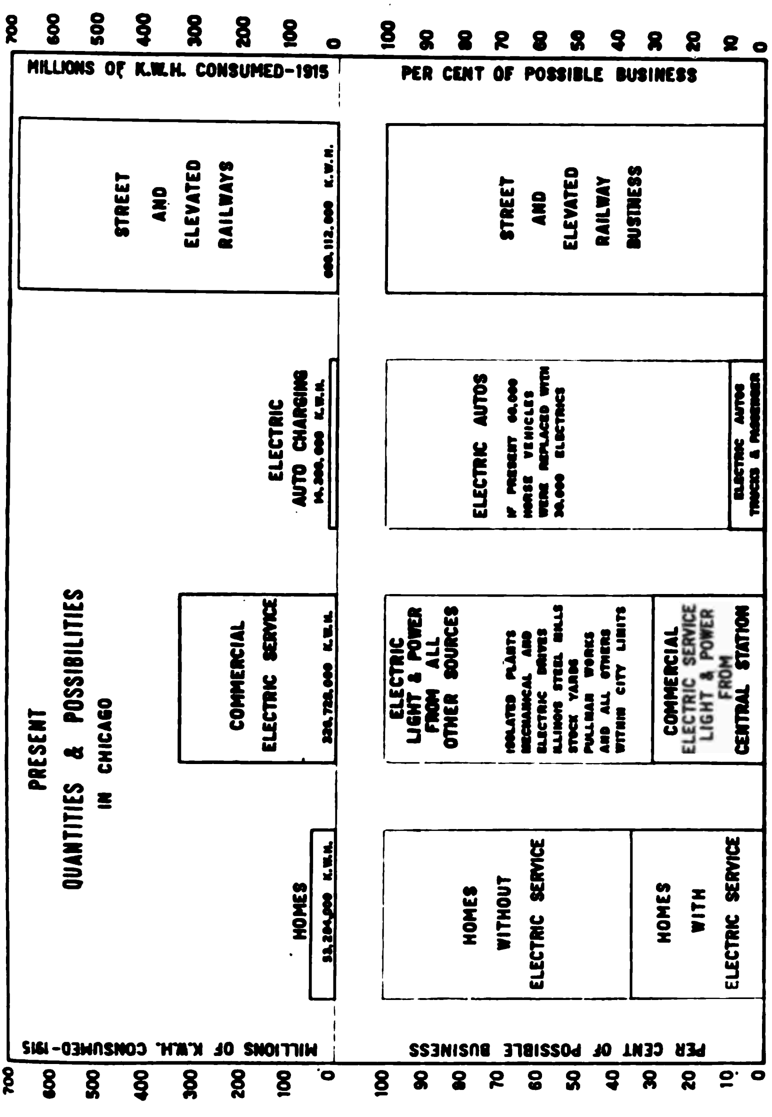

PRESENT
QUANTITIES & POSSIBILITIES
IN CHICAGO
MILLIONS OF K.W.H. CONSUMED-1915
0
100
200
300
400
500
600
700
STREET AND ELEVATED RAILWAYS
680,112,000 K.W.H.
ELECTRIC AUTO CHARGING
14,300,000 K.W.H.
COMMERCIAL ELECTRIC SERVICE
326,728,000 K.W.H.
HOMES
53,284,000 K.W.H.
PER CENT OF POSSIBLE BUSINESS
10
20
30
40
50
60
70
80
90
STREET AND ELEVATED RAILWAY BUSINESS
ELECTRIC AUTOS
IF PRESENT 60,000 HORSE VEHICLES WERE REPLACED WITH 30,000 ELECTRICS
ELECTRIC AUTOS TRUCKS & PASSENGER
ELECTRIC LIGHT & POWER FROM ALL OTHER SOURCES
ISOLATED PLANTS MECHANICAL AND ELECTRIC DRIVES ILLINOIS STEEL MILLS STOCK YARDS PULLMAN WORKS AND ALL OTHERS WITHIN CITY LIMITS
COMMERCIAL ELECTRIC SERVICE LIGHT & POWER FROM CENTRAL STATION
HOMES WITHOUT ELECTRIC SERVICE
HOMES WITH ELECTRIC SERVICE

Fig. 9

The curve shows that since 1904, when the advantages of central station power supply began to be better appreciated by the community, the average rates for lighting decreased steadily.

While the cost of electricity for lighting decreased 70 per cent of the cost of living, such as food, clothing, rent, taxes and coal, based on U. S. Government and other authoritative reports, increased on an average more than 40 percent. During this period other users of electricity also received some benefits in rates. Figure 8 indicates that the income from electric railways for energy increased from $27 030 in 1902 to over $5 000 000 in 1915. During the last nine years of this period the average rate to railways at 40 percent load factor for untransformed energy at their sub-stations decreased 26 percent largely because of the greatly increased quantity.

Practically all of the many customers between these two extremes have also enjoyed corresponding reductions in rates.

POSSIBILITIES FOR ADDITIONAL SERVICE

Notwithstanding the very large amount of energy distributed by the electric utility in Chicago, about 480 k. w. h per capita per annum in 1915 the possibilities for the future are still very great and are illustrated in Fig. 9. The upper portion shows the amount of energy distributed for different purposes in 1915 to be as follows:

Homes	53 284 000 k. w. h.
Commercial Electric Service	326 728 000 k. w. h.
Electric Auto Charging	14 300 000 k. w. h.
Street and Elevated Railway	680 112 000 k. w. h.

The lower portion of the chart shows the percentage of the present service to the ultimately possible to be as follows:

Homes	35%
Commercial Electric Service	30%
Electric Auto Charging	10%
Street and Elevated Railway	100%

One of the principal reasons for the fact that only 30 percent of the commercial electric service is supplied by the electric utility, is that the remaining 70 percent contains a considerable number of unusually large industrial establishments, such as the Illinois Steel Company Mills, Union Stock Yards, Pullman Car Works and others; also that in this 70 percent is included a great number of establishments which still have mechanical drive. Even if only one-half or say 350 000 000 k. w. h. per annum were supplied by the electric utility the advantage to the community would be considerable. Among them would be earlier and greater possible reduction in general retail rates, less smoke and dirt, less hauling of coal and ashes, conservation of coal and other advantages. It is for the best interest therefore of every retail user, present and prospective, that additional wholesale customers be secured by the utility. In other words such procedure is in the public interest. Why then are there not more boosters? Simply because the public does not yet understand this complicated and still rather new electric utility. It is a matter of personal interest and of public duty for engineers and business men to study this matter carefully and to discuss it fairly and intelligently with their neighbors and friends. The solution of this problem lies partly with you. On the other hand, the possible benefits will go largely to you and to the community. This is particularly true under the system of Public Service Commissions already adopted in some form by nearly all of the states.

POWER FOR ELECTRIFICATION OF STEAM RAILWAY TERMINALS

An additional possibility for a large amount of electrical energy that could be furnished very economically by some electric utilities is that required for the electrification of steam railroads. A committee of the Chicago Association of Commerce, in 1915 made a very exhaustive report on the subject of smoke abatement, and incident thereto the electrification of railway terminals was considered. The problem thus presented then became one of electrification as a whole, and this was reported as not financially feasible at this time. It involves electrification of some 3500 miles of single track, the traffic on some of which might have been and probably was sufficiently dense to justify electrification. On a very large portion, however, of such trackage the traffic was very intermittent and by itself would probably not justify electrification for some years at least.

The above mentioned report from which the data in Tables

3 and 4 is taken, contained complete calculations on electrification on the basis of a 2400-volt direct current system and also on the basis of an 11 000-volt alternating current, single phase system.

In Table 3 is shown the estimated substation and power loads for the 2400-volt D. C. system.

TABLE 3. SUBSTATIONS AND POWER STATION LOADS, 2400-VOLT D. C.

Substation No.	*Average Hour*	*Maximum Hour*	*Load Factor Percent*
1	1 273	2 444	52.1
2	1 866	5 309	35.2
3	7 308	10 019	73.0
4	20 207	30 007	67.4
5	16 782	26 348	63.7
6	5 914	7 493	78.8
7	10 700	15 515	69.0
8	6 410	11 391	55.3
9	3 684	6 171	59.7
10	866	2 177	39.8
11	497	2 485	20.0
Power Station	78 608	125 700	62.5

NOTE: Substation loads are at high-tension terminals of stepdown transformers.

Power station loads are at low-tension terminals of stepup transformers.

If the energy required were purchased from the electric utility it could even at this time, be supplied from four different and large modern interconnected power houses already in existence the locations of which were previously shown in Fig. 2. This would result not only in a saving in cost of transmission system, but also largely increased reliability of service.

The amount of electrical energy required by the different railroads during the maximum hour, varies from 126 k. w. for one of the industrial railroads to 23 438 k. w. for the Chicago and Northwestern Railway as shown in Table 4. This refers to kilowatt hours in the maximum hour, as required at the electric locomotive or motor car. The maximum demand corresponding to this maximum hour, after allowing for transmission and conversion losses, is 29 200 k. w. at the power house. This, the largest

TABLE 4.—ENERGY REQUIREMENTS AT PANTOGRAPH—2400-VOLT DIRECT CURRENT SYSTEM BY ROADS

(Basis of 1912)

Railroad.	Average Day		Average Hour	Maximum Hour		Load Factor
	Kilowatt-Hours	Per Cent. of Total	Kilowatt-Hours	Kilowatt-Hours	Per Cent. of Total	
1	2	3	4	5	6	7
Atchison, Topeka & Santa Fe Railway	20 537	1.38	856	1 325	1.21	64.6
Baltimore & Ohio Railroad	29 333	1.97	1 222	1 604	1.47	76.2
Baltimore & Ohio Chicago Terminal Railroad	35 355	2.38	1 473	2 067	1.89	71.3
Calumet, Hammond & Southeastern Railroad	2 217	0.15	92	148	0.14	62.2
Chesapeake & Ohio Railway of Indiana	3 016	0.20	126	349	0.32	36.1
Chicago & Alton Railroad	24 388	1.64	1 016	1 589	1.45	63.9
Chicago & Calumet River Railroad	2 407	0.16	100	137	0.13	73.0
Chicago & Eastern Illinois Railroad	26 400	1.77	1 100	1 890	1.73	58.2
Chicago & Erie Railroad	3 640	0.24	156	885	0.81	17.6
Chicago & North Western Railway	288 228	19.37	12 010	23 438	21.46	51.7
Chicago & Western Indiana Railroad and the Belt Railway of Chicago*	113 567	7.63	4 732	6 915	6.33	68.4
Chicago, Burlington & Quincy Railroad	67 655	4.54	2 819	6 464	5.92	43.6
Chicago Great Western Railroad	9 704	0.65	404	885	0.81	45.6
Chicago, Indiana & Southern Railroad	3 126	0.21	130	663	0.61	19.6
Chicago, Indianapolis & Louisville Railway	11 812	0.79	492	1 054	0.96	46.7
Chicago Junction Railway†	49 638	3.33	2 064	2 746	2.51	75.2
Chicago, Milwaukee & St. Paul Railway	130 512	8.78	5 438	8 117	7.43	67.0
Chicago, Rock Island & Pacific Railway	70 046	4.71	2 919	6 035	5.52	50.2
Chicago Short Line Railway	1 950	0.13	81	126	0.12	64.2
Chicago, West Pullman & Southern Railroad	8 260	0.55	345	426	0.39	81.0
Elgin, Joliet & Eastern Railway	40 318	2.71	1 680	2 526	2.31	66.5
Grand Trunk Western Railway	19 348	1.30	806	1 410	1.29	57.2
Illinois Central Railroad	140 521	9.45	5 855	12 021	11.01	48.7
Illinois Northern Railway	4 043	0.27	168	288	0.26	58.3
Indiana Harbor Belt Railroad	6 999	0.47	292	894	0.82	32.7
Lake Shore & Michigan Southern Railway	100 747	6.77	4 198	7 225	6.61	58.1
Michigan Central Railroad	42 092	2.83	1 754	2 386	2.18	73.5
Minneapolis, St. Paul & Sault Ste. Marie Railway	5 729	0.38	239	605	0.55	39.5
New York, Chicago & St. Louis Railroad	21 617	1.45	901	1 344	1.23	67.0
Pere Marquette Railroad	13 311	0.89	555	1 086	0.99	51.1
Pittsburgh, Cincinnati, Chicago & St. Louis Railway	56 444	3.79	2 352	3 354	3.07	70.1
Pittsburgh, Fort Wayne & Chicago Railway	95 051	6.39	3 960	6 467	5.92	61.2
Pullman Railroad	2 838	0.19	118	254	0.23	46.5
bash Railroad	37 711	2.53	1 571	2 535	2.32	62.0
tals	1 488 559	100.00	62 023	109 258	100.00	....

ludes Chicago Union Transfer Railway. †Includes Chicago River & Indiana Railroad.

requirement of any one of the railroads, is less than the rated capacity of any one of four units in service or under construction in the existing power houses of the electric utility. It is not probable that the maximum demand of each railroad would fall on the same day and hour as the maximum load of the electric utility. The maximum demand of all electrical energy on the electric utility, except a portion of that used in manufacturing establishments is fixed largely by the habits and prosperity of the people in the city. The maximum demand of the energy used by a large railroad terminal would probably be fixed by the freight traffic on such system, and which, in the Mississippi Valley and beyond, is likely to occur in October or November.

If the railway terminals of Chicago are electrified, singly or in groups, those with the denser traffic will naturally be electrified first. Such railroad, or groups of railroads, could purchase just the amount of energy required to move their traffic. This would be a distinct advantage over building a power house for future requirements, and which would naturally involve, with proper reserve, a very considerable amount of unproductive investment during the early years of electric operation of such terminals. In other words, such electrified terminals, if supplied from a new power house for this exclusive purpose would have to be operated under a handicap from the very beginning. In addition to this, the railroads by purchasing their power would be relieved from the burden of financing the power supply portion of the project. Most important of all, however, is the fact that in the end the public of the terminal city and the public using the railroad would be benefited by the purchase of the energy needed for electrification. Moreover, if the electrification of the railway terminals required a period of from ten to twelve years, from the time that the first electric trains were operated until the final completion of the electrification, then the amount of additional generating equipment required each year by the electric utility in Chicago would be so small relatively as to almost come within the limits within which it is possible to estimate the growth of the business of the electric utility.

RELATION OF PUBLIC TO ELECTRIC LIGHTING

But let us return again to the residence service portion of the business. After all that is the portion that is most conspicuous to the general public. That is the portion of the business that affects, even though to a small extent, the pocketbook, of say one-third or more of the voters of a city and eventually of nearly all the voters.

TABLE 5. INCREASED USE OF ELECTRICITY IN APARTMENTS AND HOUSES

October, 1908-October, 1915, Inclusive

	Number of Customers	*Avg. Kilowatt Hours per Customer*
Apartments.		
October, 1908	25 900	15.6
1909	37 940	16.6
1910	51 760	18.5
1911	67 806	18.0
1912	86 462	21.0
1913	110 649	24.2
1914	126 000	22.5
1915	141 620	22.9
Houses.		
October, 1908	5 232	30.0
1909	6 755	31.8
1910	9 135	33.4
1911	11 671	34.6
1912	12 912	37.6
1913	16 549	43.0
1914	19 492	29.8
1915	34 756	29.2

The average residence customer is unconscious of the fact that he is using more and more electricity, as is indicated in Table 5. This table is the result of a very careful analysis of the bills of all residence customers for each October from 1908 to 1915 inclusive. The month of October was selected as this is a fair average month and is believed to represent nearer than any other month about one-twelfth of the annual use by residence customers. In October, 1908,—25 900 customers living in apartments used an average of 15.6 kilowatt hours per customer. In October, 1915,—141 620 customers used an average of 22.9 kilowatt hours each.

This means during 8 years an increase of approximately 50 percent in the average kilowatt hours used in October by customers living in apartments. Strangely enough, the average used by customers living in houses has not increased materially during this period. However, the number living in houses is very much smaller. The increase in the number of houses was partly brought about by annexation and additional territory served and the results of increased use of electricity in houses are, therefore, not as dependable as the results from apartments.

A part of this increased use of electricity in homes is undoubtedly due to use of household appliances. These are rapidly becoming more popular. Their use lessens the burden of housework very greatly and saves women's health and strength. Electricity is thus utilized to fill a real economic need to the individual and to the nation. The possibilities for further use of appliances are however, very great. One illustration of this fact is that so far in the United States, the total number of electric irons sold are about 3 026 000. The next most popular electric appliance seems to be the electric fan, about 1 600 000 in number; Vacuum Cleaners total 470 000; Toasters 412 000; Disc Stoves 235 000; Washing Machines 212 000, these being the numbers sold respectively prior to 1916. The total number of all other electric appliances sold prior to 1916 is only 445 881. Electric irons are cheap and convenient and pave the way for other labor saving appliances. These mean convenience. In their homes, people want convenience and light.

It is the history of the human race that more and more light is wanted, and while we may not have reached, we are approaching, it would seem, the limit of glare. We have, however, by no means reached the limit of electricity required for uniform and good lighting for decorative purposes or for various tints in electric lighting. It is quite possible that at an early date the householder may purchase or telephone for incandescent lamps giving sunlight effect or giving an amber tint or a rose tint. The gas filled lamps in the market the past year lend themselves very well to such development. Many customers, especially the ladies. desire a few dipped lamps for some rooms. They do not object to the 10 percent or more loss of light by absorption in such special cases if they secure the effect desired.

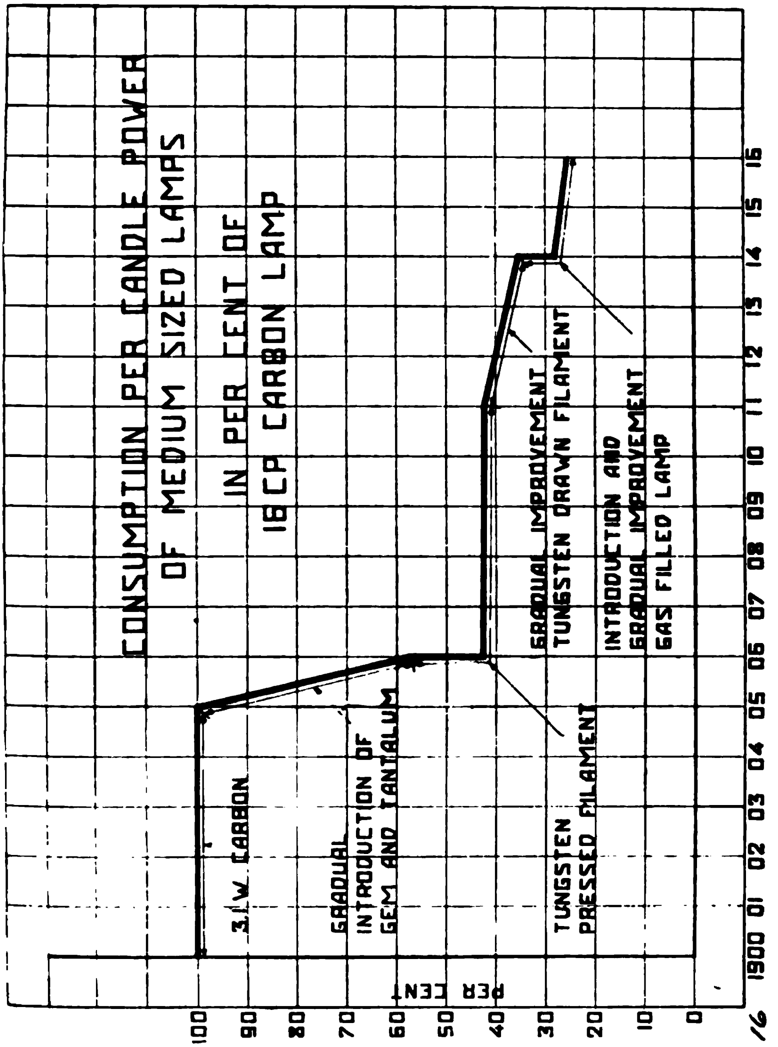


Fig. 10

IMPROVEMENT IN LAMPS

The improvement in efficiency of incandescent lamps has been very rapid in the last ten years. The gradual introduction of Gem and Tantalum lamps reduced the consumption per candle power to about 42 percent of the 3.1 watt 16 candle power carbon lamp. The further improvement in tungsten drawn filament and the introduction and gradual improvement of the gas filled lamp has been such that the consumption of energy now is only about 25 percent of the energy required by a 3.1 watt carbon lamp giving the same candle power. This is illustrated in Fig. 10. In addition, the life of the lamps has been more than doubled, adding very greatly to the convenience of the customer whose lamps need be renewed only one-half as often as formerly.

The question of lamp policy is a most important problem. The quality of the lamp affects to a very marked extent the quality of lighting received by the customer. It is the one tangible portion of electric service that comes most strongly to the customer's attention. The customer feels that he is able to judge that element of the service and yet it is a matter on which even experts, without the use of any instruments, might differ from 50 to 100 percent, unless, of course, they had a very high efficiency and a very low efficiency lamp of same wattage side by side. Without instruments it is almost impossible to compare the amount of light received one year in a home for a given expenditure of money, with that received during the same month one or two years earlier for the same expenditure of money from less efficient lamps.

The amount of light which $1.00 would buy over a long period of years is shown in Fig. 11. Prior to 1898 one dollar would buy about 1200 candle hours. This has increased during the past 17 years so that in 1915 one dollar would buy about 15 000 candle hours. During this period the rate for electricity decreased 67½ percent and the lamp efficiency increased 346 per cent. The above is based on average retail lighting rates and on 3.1 watt carbon lamps in 1898 and 1.03 watt vacuum tungsten lamps in 1915. These facts are determined in an absolutely accurate scientific manner, and yet how few customers would appreciate that in 1915 they were getting 15 times as much light for

$1.00 as they were 17 years ago. This is another of the many problems whose only solution seems to be a constant campaign of education and publicity.

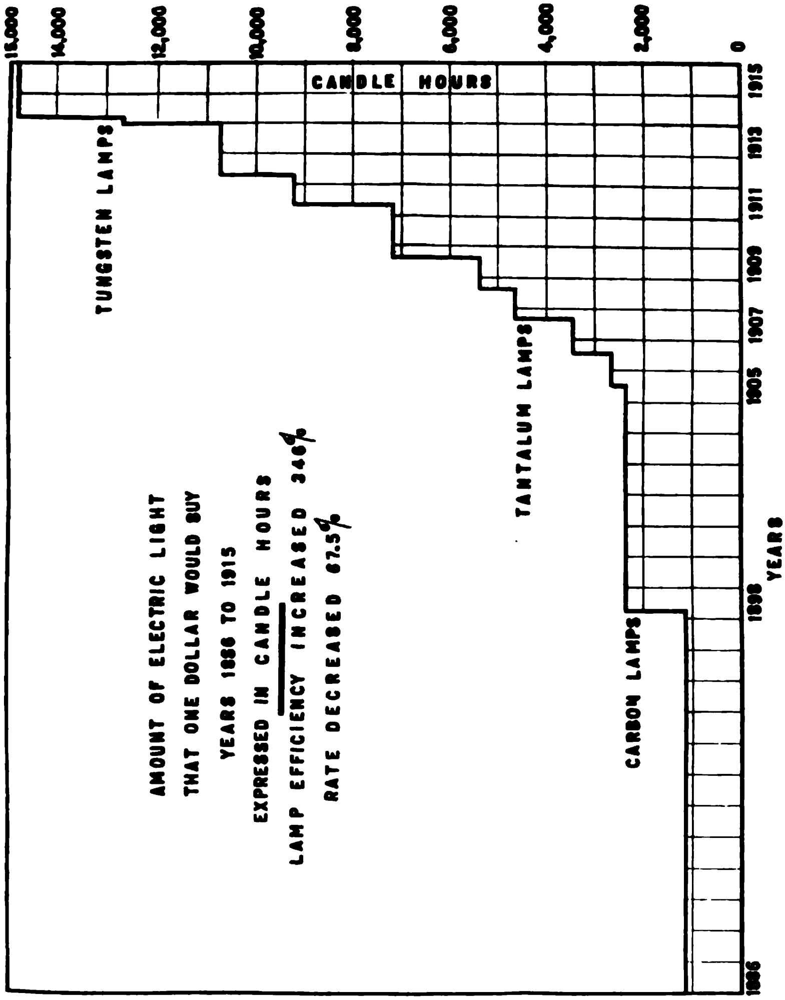


Fig. 11

USE OF TELEPHONE IN RENDERING SERVICE

There are, however, some elements of electric service that customers can judge with reasonable accuracy; that is, the promptness or lack of promptness with which their requests for service are complied. Such requests, many of which are made at moving time, often emanate from persons who are already nervous or worried about their own particular and immediate affairs. In many cases they have forgotten to make application for electric service until the very last minute. They are, of course, entitled to the most courteous and prompt attention and to due allowance for their possible state of mind. It is, therefore, not only a duty, but, it is also good business for the electric utility to make every effort to give the customer the best possible attention. In a large city the number of people who come to headquarters or branch offices of the electric utility to make arrangements in person for service, is becoming smaller and smaller. Those who use the telephone for this purpose are constantly increasing in number. Some electric utilities have therefore given much attention to the matter of telephone communication with their customers. In one instance, an electric utility in a large city has concentrated the telephone contact with its customers in three principal bureaus, known as the Application Bureau, the Service Bureau and the Customer's Account Bureau. When the customer first calls for the electric utility he is connected by the Telephone Company with the electric utility's main exchange board, shown in Fig. 12. This board contains 20 positions and during 1915 handled 7 000 000 messages. When connected with this board, if the customer does not call for a particular bureau or make his wants definitely known, the telephone operator ascertains quickly and tactfully whether the customer wants to make an application for new service or whether he wishes lamps or other service, or whether he wants information regarding his account. The customer is then connected quickly with the proper one of these three principal bureaus. This arrangement is illustrated in Fig. 13.

During the busiest hour of April 29th, 1915, there were 1425 incoming calls, of which 562 or 10 per minute were trunked to the Application Bureau. All of these calls were requests for service in new buildings or for reconnection in old buildings. There were 425 calls or 7 per minute trunked to the Service Bureau in the same hour. These were for lamp renewals, replacement of fuses, minor repairs, and the like. There were also 50

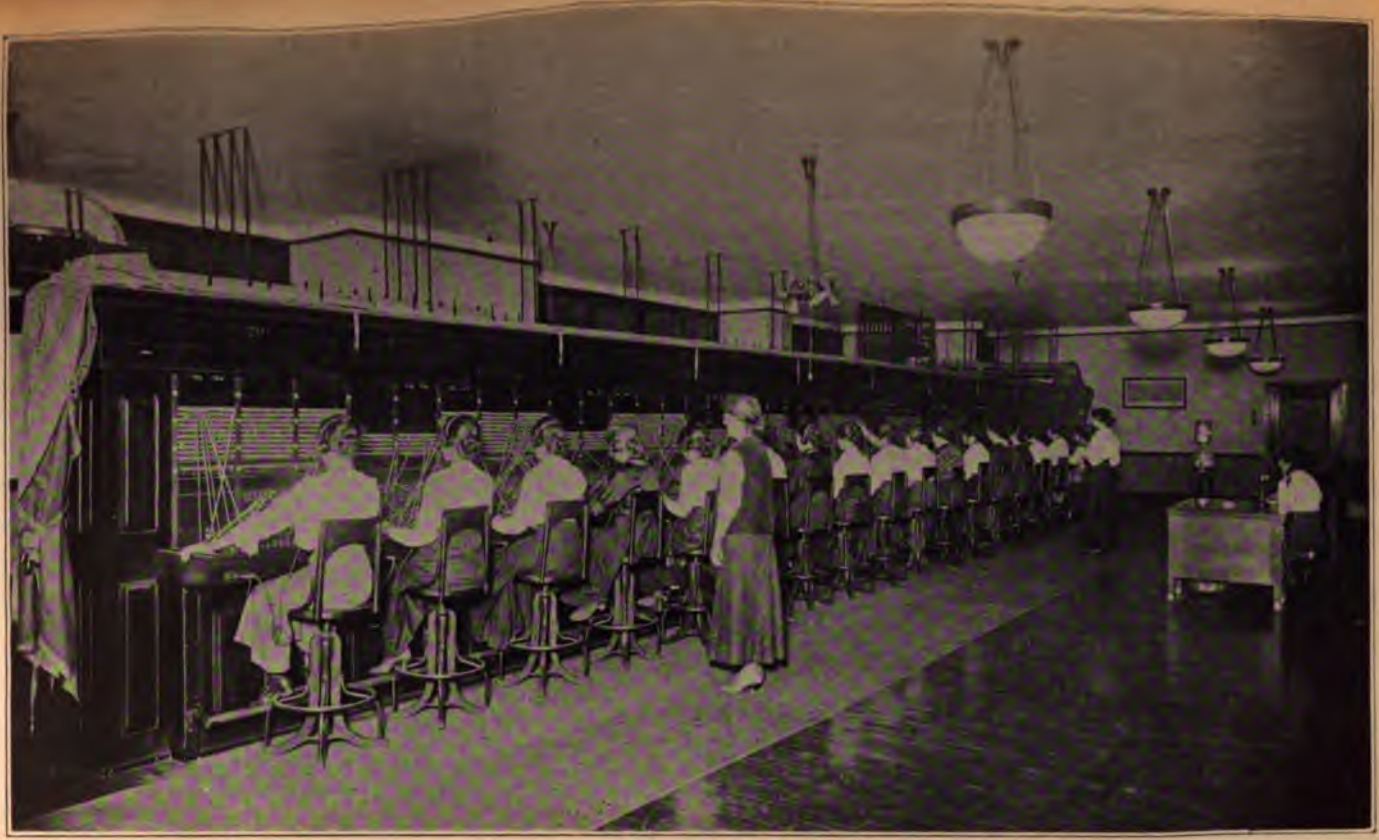


Fig. 12

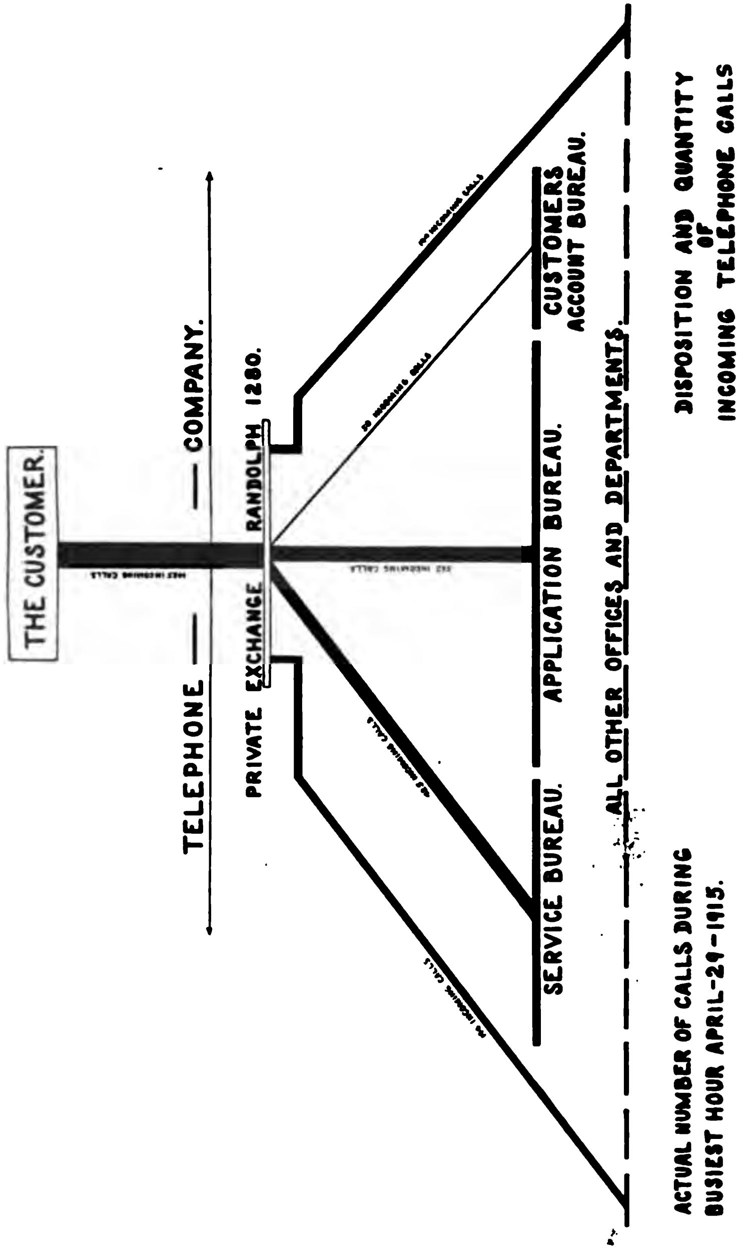

THE CUSTOMER.
TELEPHONE — COMPANY.
PRIVATE EXCHANGE RANDOLPH 1280.
50 INCOMING CALLS
SERVICE BUREAU.
APPLICATION BUREAU.
CUSTOMERS ACCOUNT BUREAU.
ALL OTHER OFFICES AND DEPARTMENTS.
ACTUAL NUMBER OF CALLS DURING BUSIEST HOUR APRIL-29-1915.
DISPOSITION AND QUANTITY OF INCOMING TELEPHONE CALLS

Fig. 13

Fig. 14

incoming calls for the Customer's Account Bureau. These requests were mostly for final bills for people who had moved to a new location, and in some cases for duplicate bills.

The Application Bureau, as shown in Fig. 14, consists of a 20 position table operated by experienced electric salesmen. There is an auxiliary 12 position table not shown in this photograph, which makes a total capacity of 32 operators to receive simultaneously 32 calls from customers desiring service. These order tables have signal lights that indicate in the vertical cabinet at the end of the table when a call is placed on the Bureau together with a buzzer signal, and any of the 20 operators on the table not busy can answer any call on the table affording a very flexible arrangement. A single operator on this order table has been able during the busy period to handle over 225 applications a day. This has a tendency to greatly expedite the rendering of service, as the experienced operator, in a tactful way, can secure exactly the information needed, which is not possible in many instances where requests are made by mail.

There is a 20 position table, as shown in Fig. 15, in the Service Bureau. The four operators at the extreme left end of the table are called Work Dispatchers, who are in touch with the individual repairmen in various districts of the city, and when calls for fuses or repairs on wiring or household appliances are received they are recorded and dispatched by the carrier system directly over the table from the operators on the Service Bureau Board to the Work Dispatchers, who sort them according to such districts, and transmit them hourly to the repairmen in the district. The lamp renewal requests are also assorted and then assigned to delivery routes for the next day. On December 20th, 1915, 2880 calls of various kinds were handled by this Service Bureau in that one day. The number of calls handled per day averages about 1950 throughout the year.

The order tables in these three bureaus are not completely manned at all hours, operators being recruited from the clerical divisions of the departments in charge of the bureaus, and being kept available during the rush periods of the day on these boards.

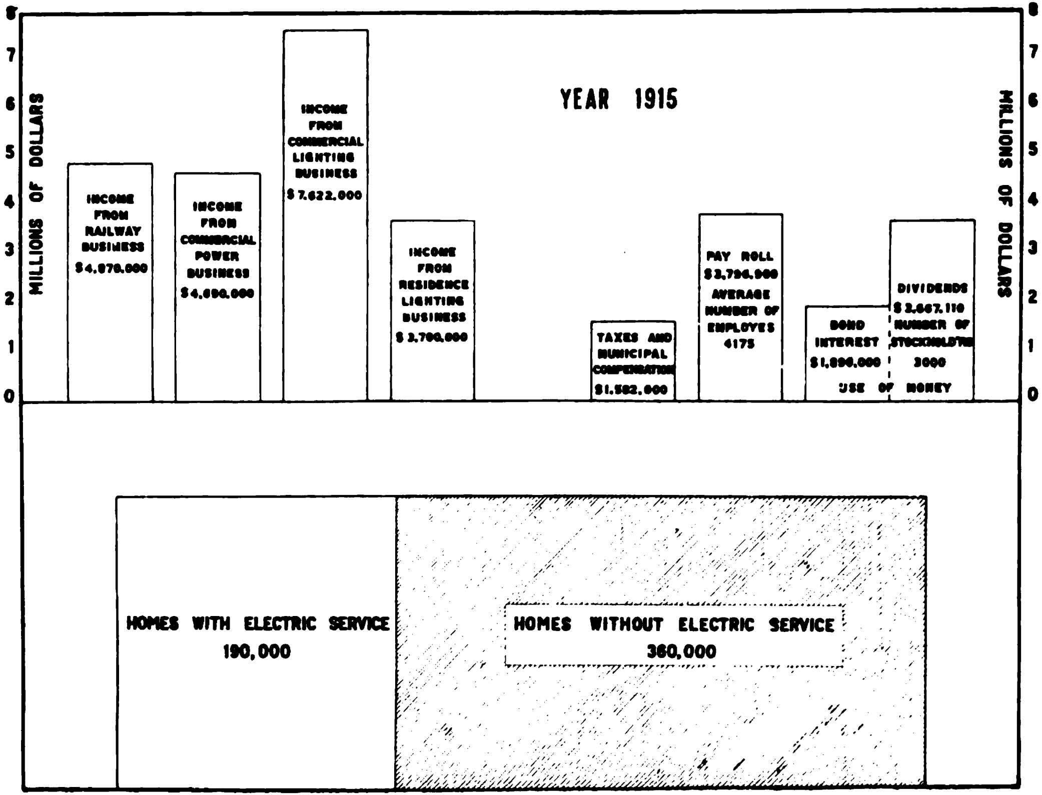

YEAR 1915
MILLIONS OF DOLLARS
0
1
2
3
4
5
6
7
8
INCOME FROM RAILWAY BUSINESS $4,870,000
INCOME FROM COMMERCIAL POWER BUSINESS $4,690,000
INCOME FROM COMMERCIAL LIGHTING BUSINESS $7,622,000
INCOME FROM RESIDENCE LIGHTING BUSINESS $3,700,000
TAXES AND MUNICIPAL COMPENSATION $1,582,000
PAY ROLL $3,796,000 AVERAGE NUMBER OF EMPLOYES 4175
BOND INTEREST $1,896,000
DIVIDENDS $2,667,110 NUMBER OF STOCKHOLDERS 3000
USE OF MONEY
HOMES WITH ELECTRIC SERVICE 190,000
HOMES WITHOUT ELECTRIC SERVICE 360,000

Fig. 16

PUBLIC RELATIONS

The greater portion of refinements in service are occasioned by the residence customers. They are in the majority. In the last analysis they are ultimately in control. These residence customers in one large city, however, as shown in Fig. 16, do not provide enough gross income to even meet the electric utility payroll. This payroll refers only to direct labor, continuously employed and carried on payroll of the electric utility. It does not include a very large amount paid annually for labor on contractors' or manufacturers' payrolls. This payroll of the electric utility is almost the same as the amount paid in dividends and bond interest for use of money. The income is divided as follows:

Residence Customers	17.8%
Commercial Lighting	36.5%
Commercial Power	22.4%
Railway Power	23.3%

The taxes and municipal compensation are almost equal to one-half the income from residences.

The residence rather than the commercial customers are hardest to please. They want the lowest possible rates and the best possible service. They are unquestionably entitled to both if not carried to a point where it is against their best ultimate interest. If, for instance, residence rates are forced so low and quality of service forced so high that substantially all residence customers were served at a loss, the commercial and industrial customers might temporarily bear the extra burden. A part of the cost of the electric service for residences would then appear in increased price of provisions, clothing, amusements and so on. Furthermore, this extra burden would mean that some industrial and commercial customers might then install independent plants and the electric utility would certainly not be able to get so many new wholesale customers. This would mean less income, less profits and certainly less chance for reduction in retail rates, if not an increase in retail rates. In a considerable number of instances State Public Utilities Commissions have found it necessary under such circumstances to raise retail rates. In those cases the forcing of retail rates too low and of service too high has been directly

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against the best interest of the residence customers and of the community whose credit standing and integrity have thereby been impaired.

In many cases State Commissions have encouraged and even directed the electric utility to lower its wholesale rates with a view of increasing the volume of its business, and by this means finally to get into a position where it would be possible to reduce retail rates. It is, therefore, for the best interest of every retail user and of every other user of electric service that additional customers be secured by the electric utility. This is true, first, from the standpoint of increasing the density of customers and thus converting unprofitable blocks into more profitable blocks, and second, from the standpoint of additional income from any customer served at a profit.

The supplying of all electrical energy needed for every purpose in any community or area from a single electric utility has been demonstrated again and again as being the correct economic solution. The greatest single problem remaining is the promulgation of mutual confidence and understanding. Engineers and business men are capable of carefully analyzing conditions, problems and possibilities. They can do much for their respective communities. Is it then not their duty to analyze, to understand and to take a firm position in favor of what is right and sound from a broad economic standpoint?

DISCUSSION

MR. R. S. ORR:* I have only a word or two to say. First, I want to compliment Mr. Junkersfeld for his admirable paper. He has stated in the clearest possible terms, and without much technical phraseology, matters that ordinarily are treated in a very technical way and are, therefore, very hard to understand. He has expressed in a most satisfactory way the reasons for the difference in cost between wholesale power and factory service and residence service. That is a matter that I find in my dealings with the public is very little understood.

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*General Manager, Duquesne Light Company, Pittsburgh.

In the first part of the paper Mr. Junkersfeld gave you some statistics as to the wonderful growth of the central station business in Chicago. He is a very modest gentleman, and I think I should supplement what he has told you by saying that the Commonwealth Edison Company is the largest central station company in the world and operates the largest steam power plant in the world. What he has stated as taking place in Chicago in the last twenty years has been going on all over the United States, only in a little less degree.

My connection with the light and power business in Pittsburgh has covered only about twelve years. At that time the central station here had, as I recall it, a power plant capacity of 18 000 k. w. Today it has 105 000 to 106 000 k. w. in service, and has on order two additional units, one of 15 300 k. w. and another of 40 000 k. w., which will be delivered and installed during the year. The data that Mr. Junkersfeld has given will give you an idea of the important place that the central station has today in every community. It seems to me that it is the greatest factor available in any community to bring about quickly its fullest industrial development.

The author has referred to the diversity factor. I do not recall whether he referred to two other points that should be taken into account in that connection. One is that with the installation of units of large capacity the investment cost per kilowatt is very much below what it is if the units are small. The other is that the efficiency of the larger units is very much above that of the smaller units. So that there is ample economic reason, in addition to this element that he has referred to as diversity factor, for the central station to become more and more the important factor in the industrial development of every community.

Mr. E. D. Dreyfus: From the standpoint of general knowledge on the part of the engineering fraternity, and the public especially, the underlying factors of the central station industry is too little understood. It is, therefore, particularly fortunate that we have been able to enjoy a discourse on the subject by one who stands out prominently as an authority in this field. The paper is further enhanced in value by his candid consideration of the essential elements of electric lighting service. Mr. Junkersfeld has brought out clearly the important financial position occupied by the electric utility. If we do not reflect seriously upon this amount of $2 000 000 000 investment, we are apt to consider this industry incident to our national life instead of its being a consequential part of the whole development in this country.

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*Statistician, West Penn Traction Company, Pittsburgh.

The public utilities, though in their infancy as compared with other established industries, are more and more becoming the very vertebra of our social and commercial activities. This is represented rather forcibly by the ratio the total investment in public utilities bears to our total national wealth. Adding the valuation of the other utilities (gas, street railway, telephone, water works and kindred service), but exclusive of steam railroads, the sum exceeds ten billion dollars and, including steam railroads, it stretches beyond twenty-five billions. Compared then with the total national wealth, which the Census Bureau at Washington estimated at $187 739 000 000 for 1912, the position of the utilities stands out most prominently. Real property, or the value of improved lands, was one-half this total wealth, so that with respect to constructive development and resources, the utilities represented over 25 percent in value. The utilities, as a whole, therefore, must command the most thoughtful consideration, not alone by any selected group of men, but by the public in general. It is evident that when the status of the utilities is disturbed you will find that the entire fabric of the industrial world is shaken. We had a very forceful example of this condition in the railroad rate cases of a year or so ago, and we must remember that the other utilities (electric light, telephone, gas, electric railway and similar public service companies) play a correspondingly important part in promoting the progress of the community.

The speaker has illustrated fully the magnitude and scope of the central station industry as well exemplified by developments in Chicago. As a point of interest to people of this vicinity, it may be well to mention that there are stretches of power transmission lines almost unbroken in length for upwards of two hundred miles either way.

And with the extension of these power arteries and filling in the few remaining gaps, it is safe to predict that within a very few years it will be possible to deliver power to such a line from one of the gigantic Chicago power stations and transmit the energy to New York City, if this were to be economically profitable. The practical situation, however, will be that along these trans-continental lines, as we soon may term them, we will have located various modern generating plants, all contributing toward a maximum guarantee of service continuity and a minimum of investment requirements. This will inevitably induce the steam railroads to take up electrification at earlier periods, as they will be assured of a substantial supply of propelling power at low costs and may accordingly devote their entire funds to more profitable use in road equipment, as the author definitely brought out.

The speaker noted the very short term of service of some of the early turbines installed in the Fisk street station. This is typical in many ways of the development that has taken place in the electric lighting field, and equipment has consequently been withdrawn from use to give way to more economical installations long before their original cost could have possibly been written off the books.

This factor too frequently is lost sight of, as I grasp it, when we come to regulate public utilities, and thereby punish them for preparing to render a bigger and better service simply because the property is no longer "used and useful for public convenience." Time has not allowed me to illustrate this point as I would very much like to have done. It could have been shown in an illuminating way. But right at this point I make my feeble appeal to the intelligent public, and particularly the engineering profession as a body, to assist in building up constructive thought in matters of public service regulation, and not permit iconoclastic and ideal reformers to upset conditions on purely theoretical lines. There are the same practical elements in the utility enterprises as is in every other business, but the public seems to lose sight of this when it becomes inflamed against the public service company. Before concluding, I wish to make casual reference to one way in which exceedingly unfair and woefully distorted criticisms are hurled against the privately owned utility. In an open meeting in this city recently a public officeholder declared rather derisively that the people were being mulcted because the residential consumers were obliged to pay ten cents per kilowatt-hour for the service they received, while, on the other hand, the company had contracted with the city on the basis of bulk supply at one cent per kilowatt-hour or better.

Let us analyze the impropriety of such random and reckless statements. In looking over some of my old notes today I ran across a little data on the cost of maintaining consumers' accounts and, although more or less fragmentary and applied to conditions in a northwestern locality, it may be properly employed to reveal the rational difference of the charges for those consumers who buy in small quantity and those who buy in bulk. Kindly observe the following record of the average annual cost per consumer for items of expense as herewith detailed:

Lamp renewals	$1.70
Testing meters	.56
Reading meters	.32
Installing and removing meters	.29
Maintenance of meters	.14
Answering trouble calls	.28
Operating service	.30
Operating lines and transformers	.38
Cost per customer for general expense, including salaries of officers, stationery, printing, legal expenses, damages, rents of buildings, insurance, etc.	11.33
Total	$15.80

To carry out the illustration we must take note of the fact that the average annual consumption of energy for the three main classes of users will be approximately as follows:

Residential	200 kw. hrs.
Commercial or business	2000 kw. hrs.
Large power	20 000 kw. hrs.

Then dividing $15.80 by these respective quantities we obtain the service costs for the different classes as follows:

Residential	8.0c+ per kw. hr.
Commercial	0.8c+ per kw. hr.
Large power	0.08c+ per kw. hr.

It is to be borne in mind that these amounts cover only that part of the expense dependent upon the total number of consumers, and is, more or less, clerical and supervision expense, so that there is still to be considered those costs due to generating the power and to the fixed charges upon the required investment. In a similar way these later costs bear a proportionate relation as regards the different classes when referred to the unit of consumption as previously shown. Let us also remember that in spite of the above illustration there is no precise formula for working out the rate of charge for the different classes of service.

If we are to develop the service for the business for the greatest benefit of all concerned we may follow the cost of the service theory only so far as such basis will bring about the greatest profitable employment of the supply of electricity, and then we must introduce allowances for various contributing factors such as are incident in every line of business. As attesting this fact I will quote below from a recent decision of the "*Missouri*" Public Service Commission in a railroad case which apparently "*has been shown*:"

> "The expression, 'what the traffic will bear,' has fixed in the minds of the public perhaps an improper meaning of that term. In its true significance, however, this expression sums up the answer to the problem above outlined, i. e., the proper distribution of the burden of transportation between the various commodities and classes of traffic offered for transportation. The end sought to be secured in the solving of this problem is, and must at all times under the statute be, the distribution of the burden of transportation between various commodities and classes of traffic in such manner that the total income derived from the rates charged by the carriers may afford it that compensation to which the statute declares it to be entitled, and yet at the same time permit all the varying classes of traffic to enjoy a full and free movement throughout the territory reached and served by the lines of such carriers."

MR. HENRY HARRIS:* The most impressive thing to me in Mr. Junkersfeld's paper is the fact that he is stating those homely truths that enlist the interest and sympathy of every one present. And we all of us are supposed to know these things. I was unfortunate in not being able to make notes of the paper as it was being read, but one thing that has occurred to me is this, and perhaps it is a point that some of us lose sight of. In the development of the electrical industry I always try to keep in mind that originally the electrical business was a lighting business. Thirty years ago the electric public utility business was a lighting proposition. We developed the lighting business for a period of years and we had a load only of several hours' duration, and it was quite some time before we awoke to the possibilities of electric application for other purposes than that of lighting alone. This is probably unfortunate, because we started off with an adequate price for the given service and, while the development of other applications of electricity has made it necessary to offer lower prices for these newer applications, because of the value of the service, in comparison with the slower reduction in cost of the lighting service. This divergence is so wide that the public cannot see and cannot understand why we should offer low rates for any class of service, or so much lower rates as compared with the service with which the average citizen is familiar. Mr. Junkersfeld, by making what I may term an appeal to all of us to do our mite in educating the public to the true state of affairs in the industry, has deemed this not too unimportant to bring to your attention. There is a valid reason why the residential rate to the small consumer should be higher than the wholesale consumer. Unfortunately, he is in the majority and he cannot appreciate, just because you make that statement, that it is true; and I simply want to emphasize the point that there is a valid reason, and that we should make every effort to understand that reason and to educate the public as to the real cause for those widely divergent charges for delivery of current to purchasers in small quantities and to purchasers in large quantities. If we can drive home the fact that the only hope for a reduction in price to the large number of small consumers is the development of electrical applications demanding large quantities of energy, and that we can only expect to obtain for those large demands a price which will be a true measure of the value of that service, we will have accomplished a great deal.

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*General Contract Agent, Duquesne Light Company, Pittsburgh.

Mr. Dreyfus referred to a certain situation locally, and it happens that this paper of Mr. Junkersfeld's is very timely. It seems to me that we should all, whether interested in the electrical industry or any other, attempt to lift the cloud from before the eyes of the public, who are apt to be so easily misled when the real facts are distorted. In this connection I was very much interested in reading an editorial in a local paper, resulting from the discussion to which he referred. Speaking of the announcement of a reduction in rates to small consumers, it said that it did seem as though it would be discouraging to a public utility company to voluntarily offer a reduction in rates to a large number of consumers when the only thanks they receive is, "Why only reduce the price 10 percent; why not make it 20 percent while you are about it?" It was a very sane argument, and it should be encouraging to the management of the local electric utility to find that at least the editors of our papers appreciate the difficulties we are encountering and are willing to give credit for the effort which is being made to effect a more reasonable and equitable rate to the small user. We must drive home the fact that the only hope for a reduction of the so-called high rate for electric service is in the development of applications of electricity industrially.

While this may seem to be a rather trifling matter, yet the appeal which Mr. Junkersfeld made in closing his paper gives me the right, I think, to emphasize the point.

Mr. P. M. Lincoln:* Some weeks ago I passed through Chicago and had the pleasure of sitting down with Mr. Junkersfeld and going over some of his load curves. The thing that struck me first was the tremendous total that he had. He had a total load last winter reaching the maximum on one day of nearly 340 000 k. w. But the thing that impressed me even more than that was the fact that on the day before the exigencies of the weather or something else had made this total about 315 000 instead of 340 000, a difference of some 20 000 to 25 000 k. w. in the maximum energy put forth in one day as compared with the next. A few weeks later I was in Portland, Ore., and in going over some figures there upon the amount of power used in the west, and it was rather significant that this daily variation which Mr. Junkersfeld had in the Commonwealth Edison plant in Chicago was nearly enough to supply the whole state of Oregon. This gives a very good indication of the tremendously large plant which Mr. Junkersfeld has been dealing with and which he has described to us so explicitly tonight.

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*General Engineer, Westinghouse Elec. & Mfg. Co., Pittsburgh.

Now let me say a word about this matter of rates. It seems to me that we are unfortunate in that in all our dealing in this matter of electrical supply we always speak of the rate per kilowatt hour. It is unfortunate that we chose the kilowatt hour as the index of the cost, or the value, of the electricity supplied. I do not believe that the kilowatt hour is the true index. Mr. Junkersfeld I believe mentioned a ratio of fifteen times by which some of the rates of the Commonwealth Edison Co. exceeded some others. That of itself is an indication that the kilowatt hour is not a true index either of the cost or of the value of the electric service, and that it ought to be based upon some other index. Whether we can ever get away from this index of the kilowatt hour is a question. It is doubtful, because it is a thing that we have always been used to, and is pretty firmly established, and it is probable that we cannot entirely get away from it. But it is unfortunate that in discussing this matter with the public they always speak of electricity in terms of cost per kilowatt hour, when it is inherent that the little fellow who buys electricity in small quantities must always pay a very much larger amount per kilowatt hour than the man who takes it in very large quantities.

Before I sit down I want to thank Mr. Junkersfeld for one idea which he dropped. He gave me a new concept, the concept of a "controlled imagination." You know that quality of imagination is what differentiates the human being from the lower animal. The man who has no imagination is what an American poet has referred to as a "brother to the ox." The man who has an uncontrolled imagination is the visionary, the dreamer. The man who has a "controlled imagination" becomes the leader. I wish to thank you for that concept, Mr. Junkersfeld.

MR. C. G. SCHLUEDERBERG:* Mr. Junkersfeld spoke briefly on the subject of meters. He stated that after thirty years development, the present electrical meter is still susceptible of considerable further improvement. I would like to ask whether he refers particularly to questions of inherent design, sustained accuracy or first cost, or all of them. I think a further elaboration of his ideas would be of interest to some of us.

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*Engineer, Westinghouse Elec. & Mfg. Co., East Pittsburgh.

Mr. J. S. Jenks:* It is useless for me to attempt to elaborate what has been said by Mr. Junkersfeld and others on the matter of rates and the effect the rate has on the various consumers and the idea the small consumer has of what he considers an exorbitant rate for a commodity, or a luxury, or a necessity, or a service which he receives, all of which he considers he pays for in his monthly pittance when a very large proportion of the efforts of a large organization are put forth for the service of the little customer.

I believe that the utilities commissions of the various States have recognized that the small consumer, whose service is usually or principally a light service, demand a better service than any other consumer. For that reason they have conserved more rigid rules and regulations than have to be adhered to in any other service. They have gone farther and said that we have to take the bitter with the sweet, we have to supply the little customer, whom they recognize is not always a profitable customer and not allow the public utility to "pick the plums." They realize that the plums are not the little fellow, they are the large customer who buys energy in large quantities and if it were not for the large customer the development of the utility would still be in its infancy.

An example of that is the growth of the utility with which I am connected. Fourteen years ago when the property was simply lighting property and had practically no power service whatever, it had a demand of less than 1000 k. w. and this demand was not growing materially until we began reaching out into the power field. And as we developed we have taken on power customers of all sizes until today the lighting business is the smaller portion, we having grown in fourteen years from less than 1000 to over 45 000 k. w. This shows the possibilities of development by the aid of the large or wholesale consumer and makes possible more economical developments; hence, the thing that makes it possible to supply all customers more cheaply, depend upon large customers. It is quite true that the small consumer has received the benefit of the reduction in price, as well as the large consumer. It is also true, but seldom considered by the masses, that the cost of serving the small customer has constantly gone up, it has not been reduced as has been the cost of serving the large customer. And now the service demanded by the small consumer is more exacting and costly than ever before.

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*Vice President, West Penn Traction Company, Pittsburgh.

It used to be, when the small consumers were paying two or three times the present price for the service and five times the price for very inefficient lamps, that they were satisfied with night service only and regulation anywhere within 15 to 20 percent, while today they are demanding regulation within 1 percent and time efficiency of practically 100 percent for a service that is infinitely more costly to produce than when they paid much higher prices. You have been shown this evening the great reductions which have been made which have given the small consumer an advantage of about 15 to 1, all of which is principally due to the results obtained from the improved conditions caused by the large consumers who, with their better load factor and large revenues, have made it possible to grant the small consumer much greater reductions than have ever been given to the wholesale propositions.

There are so many factors unknown to the public which enter into the cost of supplying the little consumer that it behooves us to try to instruct and educate the public properly in regard to these matters.

MR. WILLIAM HOOPES:* In common with everyone here tonight I was greatly interested in the paper, but I am sure that I cannot add very much to what has been said. Our use of power is on a scale that is concentrated in groups so large that the problems which usually come before me are quite different from those that usually confront central station engineers. I want to take this opportunity, however, to ask Mr. Junkersfeld the load factor which accompanied the production of a kilowatt hour for 1.95 pounds of 10 000 B. t. u. coal. That seems to be a very high result and it may be interesting to large corporations using power on the order of the entire output of the Commonwealth Edison Co.

*Electrical Engineer, Aluminum Company of America, Pittsburgh.

†Such a performance in actual practice with a load factor less than unity would indicate that perhaps it is possible to make power from fuel at a cost comparable with that of water power. For the fixation of atmospheric nitrogen, the production of aluminum, and for other industrial purposes which require cheap power in very large amounts where water power as at present is considered to be the only kind available, steam power may after all prove to be cheaper in cases where an advantage in location is obtained by the use of steam power. Mr. Junkersfeld has answered my query to the effect that the load factor accompanying his stated results was 70 percent. Some of the very large consumers of power for industrial purposes have a load factor of unity, so that their conditions may even permit the attainment of a still higher result. By locating a plant close to coal mines, 14 000 B. t. u. coal can at some locations be delivered in the boiler room for $1.00 per ton. Based on the Commonwealth Edison Co. performance, only 1.4 pounds of this coal would be required per kilowatt hour, or 6⅛ tons per year. At $1.00 per ton this would cost only $6.12½ per kilowatt year for fuel. This low cost for fuel, taken in conjunction with the fact that a large steam plant costs very much less per kilowatt than the usual water power plant, points to the possibility of actually making steam power at a favorable location at even less cost than water power is produced at many already existing installations.

MR. F. UHLENHAUT:* Mr. Junkersfeld's paper covers his subject so fully that there is little to be added. The paper as a whole is splendid argument for the elimination of the isolated plant. The available power in a manufacturing city like Pittsburgh is considerably in excess of such cities as Chicago, New York or Philadelphia, exclusive of any service may be required for the electrification of steam railroads. But the difficulty we find in Pittsburgh is to convince the manufacturer who is contemplating a power installation, that a public service corporation, due to the diversity factor which Mr. Junkersfeld so admirably illustrates, can supply power with a profit, cheaper than he can generate it himself.

†Added by letter.

*Chief Engineer, Duquesne Light Company, Pittsburgh.

Mr. Junkersfeld's paper clearly states the issue, and in such a convincing way that it should be of great value to any central station going after power business.

MR. ELMER K. HILES: In looking over the paper of the evening two or three points presented themselves to me. There was the matter of simplying relations with residential customers, and I would ask Mr. Junkersfeld to go into that matter a little more in detail. And the same question that Mr. Lincoln developed, the unit of kilowatt hours, the Author indicated that the cost per customer to supply 5 customers in a city block was almost twice as great as when 50 customers were in that block, and further that fuel cost was only about 4 percent of the total cost of service. Here in the Pittsburgh District we are all interested in the fuel supply problem, the coal fields are quite a distance further from Chicago than from Pittsburgh and I will be interested to know what provisions have been made by the Commonwealth Edison Company for continuous coal supply.

MR. C. ELMER BOWN:* I can understand the attitude of the average technical man to the man in my position, because this is not my first experience in dealing with public utility problems from the standpoint of the public. The technical man is, of course, concerned primarily with the practical phases of the manufacture of his commodity. The engineer in particular is apt to lost sight of the extremely important question of the relation of the utility to the public, and to be impatient, and often with good reason, with attempts on the part of the public to regulate his business. He considers it an impertinence, an interference with something that the public is not concerned in. But after all, if you consider the practical aspects of the case this question of the relation between the utility and the public is of very great importance.

I think it is generally coming to be recognized that the utilities are not very different from ordinary businesses; they are engaged in the business of manufacturing and selling something. Street railways are selling transportation. Electric service companies sell light and power. It is true they are interested in developing the art of salesmanship for their wares; it is true they are interested in having as large a market as possible for those wares; it is true they are interested in harmonious relations between themselves and their customers. And this cooperation which the proprietors of these public utility enterprises urge on the part of the public is something that neither they nor the public can afford to neglect.

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*Advisor to Council, City of Pittsburgh.

Now, why isn't there more of. this cooperation? It is principally because the public does not understand the questions with which the proprietors and their technical men are dealing in these enterprises. Right now in this matter with which I am struggling in the city of Pittsburgh today I have learned a good deal tonight that I did not know. I came here after information and I have gotten a great deal of very interesting information. And if the utility corporations would see to it that information such as we have gotten here tonight is made more available to the public I think it would help them in the end. But a man in my position encounters such things as this, for instance. I asked a man the other day: "Is there any good treatise on the subject of making rates for electric utilities?" He said there was. "This is the best one there is." He pulled out a book and as I looked at it, he said: "I don't think you can get it." On the title page of the book were the words, "Published by the Commonwealth Edison Co. of Detroit for Private Circulation only." Is there anything in that book that I should not know, that the public should not know?

Take this question of rates for electric current. I can see even with the little that I know about this subject that it is the same struggle here as has been fought out and is being fought out in the case of the railroads today, the struggle between the theories of cost of service and value of the service. In other words, are you going to construct your tariffs on the principle of cost or of what the traffic will bear? The public does not like the expression, "what the traffic will bear," but if that is a scientific principle—and I think a good many men who have given study to these questions, particularly to the question of railroad rates, have come to think that what the traffic will bear is the scientific theory for the construction of railroad rate tariffs--

then in the end that is the principle upon which rate constructors have to build.

Now, I do not know whether that is a proper principle for the framing of electric light and power schedules or not. It may be. If it is, it is to the interest of the utilities that they be published, that the public be made aware of the reasons why that is proper and necessary. For those questions all have to be fought out. You can not dodge them.

Bear in mind that it is a principle of public service just the same as it is of public office, that it is a public trust. That has been accepted as a principle of ethics from time immemorial, and a good many of us were possibly a little bit surprised when the Supreme Court of our state a few years ago in an opinion in one of the Capitol graft cases said that that was as much a legal principle as a principle of ethics. Public office is a public trust, and no less is public service a public trust. And money that is put into these public utilities is put in with that understanding. There never has been any other principle of law than that the corporations engaged in public service are bound to render reasonable service at reasonable rates, and that means that there must be the fullest publicity of all their operations, of everything connected with their business. The public is entitled to it and the public will get it. And they will get the facts, not generalities.

Mr. President, I did not intend to speak so long as this but this is a subject which lies close to my heart, and if what I have said will help any one here to get the point of view of those of us who come to this subject from a different standpoint, I will feel repaid.

MR. F. W. H. CLAY:* The engineer does not so much need to emphasize the viewpoint of his science as different from the public's viewpoint, as he needs to pay attention himself to a still higher science,—I mean the science of psychology, which is the greatest science of all. Practical psychology is now being recognized more and more, and the engineer should understand it. Every politician is essentially a practical psychologist; every business man, consciously or unconsciously, makes great use of it; why shouldn't the engineer? For example, the wise engineer will understand how to make the public appreciate the difficulties of a great public utilities corporation. This is the third address of this kind I have heard of late, including that of Mr. Insull at the annual banquet of the Society, which struck me as having an extremely wide and somewhat heroic point of view. All these addresses exhibit a broad "constructive imagination." It would be a great thing if the engineer could go a step farther in his analysis, in recognizing that he is dealing not only with an engineering problem, but with a problem of public psychology, or the psychology of the crowd. I think he will find the solution of many of his problems in this direction. I see no reason why the engineer should not frankly show the public that if a new user of electric power installs his own lighting plant, this in the end affects the price of the light used in his own residence and yours and mine. I suggest that the engineer ought to recognize the growing public idea that the public is entitled to know the real basis of the prices, and that they are based upon physical valuation of the investment. If the public knew what was the actual investment in one of these great power service plants, and what part of the expense of the plant must be borne by the individual small consumer as compared with the cost of supplying a city for example, I do not believe the public would raise any objection to paying ten cents for individual supplies where the city pays one cent for its light. The enlightened engineer should recognize that in this field of public utilities he has to do with other problems than those of strict engineering science; he gets directly into the larger science of the psychology of the crowd. If he takes the public into his confidence I do not believe there will be anything like the friction there now is between public utilities corporations and the consumers of their product.

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*Patent Attorney, Frick Annex, Pittsburgh.

MR. JUNKERSFELD:* I feel complimented that my rambling remarks have brought forth so much discussion, particularly from men who are so eminently able to discuss the subject. With your permission, I will answer the questions in reverse order.

Mr. Bown raised the question that he thought some of the utilities looked on regulation more or less as a matter of impertinence. The records of public discussion will bear me out in saying that some of the very earliest suggestions for public regulation came from public utility operators. These suggestions did not come as a matter of philanthropy but as a matter of good business, because these public utility operators had sense enough to know that ultimately in order to make permanent the investment of the stockholders to whom they were responsible, public regulation must come. As much as eighteen years ago, it was urged publicly in an electric light association that the members of that association should conduct their business accordingly and to assist rather than oppose the gradual bringing about of public regulation. When I say public regulation, I mean reasonable regulation, not the kind of regulation that is absolutely local, or regulation that is purely a matter of driving a bargain fairly or unfairly.

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*Author's Closure.

As for proprietors of public utilities, that is another instance in which there is a great deal of misunderstanding. After all, who owns the public service corporations? I can not speak for Pittsburgh, but in Chicago 85% of the stockholders of the electric utility live in that city. Of these 41% are women. A considerable portion of the public owns that particular utility.

I agree with Mr. Bown as to the need of more information and one of the reasons why I have been speaking so frankly as I have, is because correct information should be disseminated. The public should know and understand. It is however, a complicated matter, one of the newest and least understood of the public utilities, and even expert engineers do not yet as a rule understand it thoroughly? Therefore, it seems best to give the fullest information only to bodies such as this audience who are capable of analyzing the information and who in turn honestly and intelligently disseminate such information farther and farther. You have often heard it said that a little learning is a dangerous thing, and if full information without careful verbal explanation went directly to the public, it would certainly fall into the hands of some people who would misuse the information intentionally or unintentionally. That would be unfortunate. After all, the managers of corporations are mere agents. They represent the stockholders, who are also a part of the public. The number of stockholders in public utilities has been increasing very rapidly, especially during the past five years. In this way the stock of most of the public utility corporations is being spread out farther and farther. This means better cooperation, and better understanding and is for the best interests of all in the end.

The question was also raised as to what the traffic would bear and whether or not that is a proper basis for rates. I purposely avoided that because that is a long subject. Some of the best men in the business will argue for hours that rates should be based on the value of the service, others that it should be based on the cost of the service. My own view is that both must be taken into consideration just as much as the fellow who runs the corner grocery must take into account what his goods cost and if he sells below cost he will go bankrupt. He must also take into account what the traffic will bear because if he charges too much, he will have no customers. He must sell in between those two limits.

A public utility is in a slightly different position. It must serve several different classes of customers. The public or the majority finally rules in this country. The public or the majority therefore must be served at as low a cost as possible. The majority in this case means residence customers. It would seem that no self-respecting man should care to be served below cost, which means at the expense of some of his fellow citizens. Notwithstanding this, the facts are that every electric utility in this country carries a considerable number and in some cases a very large number of residence customers below cost to serve them.

If an electric utility sells energy at a profit to a manufacturer cheaper than he could produce such energy for himself, is it not entirely proper that in that case the value of the service should be the criterion? In that event, both parties win. The more the utility gets for the service to this manufacturer, the more it is able to reduce the rates to its other customers, and therefore in that case a rate based on value of service is for the public good. For that reason the value of the service is a most important factor in the establishing of rates for many classes of customers.

Mr. Hiles spoke of simplifying the relations of customers and which was also referred to by Mr. Lincoln in his remarks about k. w. h. costs. It was pointed out to you how this k. w. h. basis of charge started. In those small noncondensing plants in small areas the k. w. h. was the best measure. That however was 30 years ago. The k. w. h. is still one of the proper measures in bulk supply. But with the residential customer the cost of coal is a very small item. In the instance I cited, it was only 4 percent of the total cost to serve. Most of the expenses, perhaps 80 percent in many cases, are in no way affected by the k. w. h. But this k. w. h. method is something we have inherited and it is very hard to get away from it.

If new electric light rates for residences were to be established today without any outstanding obligations or precedents, they would undoubtedly be based on some constant amount payable quarterly in advance and a leveling up charge at the end of six months or a year. The quarterly charge might be based on wattage connected or number of sockets or area of rooms or cubical contents of the rooms or other suitable factor. The reason it should be so based is because there is a constant item of cost in serving residences regardless of whether the customer takes a large or small number of k. w. hours. So the constant charge per quarter or per month plus a small k. w. h. charge should be the proper basis because the customer who uses flat irons or heating devices should pay a little more than the customer who does not. The charge per quarter as a constant charge and a k. w. h. charge every six or twelve months for the amount used would avoid the enormous expense of reading the meters, rendering and collecting so many small bills every month, which expense some consumer must pay for in the end. If the meter could be read once every six or twelve months, it would help a great deal in reducing cost to serve residence customers. With such a residence rate the present meters are much more accurate and hence more expensive than necessary. If only 20 percent of the bill for example is based on meter reading, then a 10 percent error in the meter would only mean 2 percent in the yearly bill. An allowable 10 percent error would mean a much cheaper meter. The meter investment charge is one of the large items in cost to serve and a material reduction in that item would help in reducing rates.

As to coal supply in Chicago. The utility had to protect itself for the future in coal supply by purchasing a large coal field in central Illinois which has enough coal to take care of Chicago for probably 100 years or more. The coal is shipped a distance of about 150 miles or more from coal fields at a point where there were several railroads that could bring coal into Chicago. There is a considerable tract of land adjacent to each station on which coal can be stored. The total amount of coal carried in storage at the power houses and at other storage yards is about 300 000 tons in bulk. There is also a large amount on the tracks so that there is always 60 days' supply of coal available, and in times of threatened coal strikes that is increased considerably.

Mr. Hoopes asked the question as to the load factor on those units that afforded an efficiency of 1.95 lbs. per k. w. h. They are the later and newer units and are running very long hours. The three most economical units that we have are running on a daily load factor of about 70 percent. Daily load factor is here used because it has the greatest influence on operating economy. When the total cost is compared, the yearly load factor should be used because interest, depreciation, etc. go on the entire year. I am giving the daily load because that more directly affects the fuel economy about which Mr. Hoopes asked.

Reference was made to the fact that in closing my paper, I made an appeal. I accept that characterization. That is just what I intended to do. I feel that is the way we can promote a better understanding by giving information frankly and talking it over among men who are capable of analyzing it and are willing to study it. That is all any reasonable public utility wants and all any public should ask. But the trouble is that very often the public are not fully informed, in fact sometimes deliberately misinformed by antagonistic newspaper publicity. In the end sound economic principles will prevail, but in the meantime much effort is required to prevent injustice and harm to a large proportion of electric service users as well as of the investing public.

If the public utility corporation is hampered unduly and its rate of return reduced below an amount where it gets a fair rate of return, it can not attract capital. No one in this room will invest money where he will not get a fair rate of return. If that rate is not obtained the cost of capital will go up and of course with it the expense of operating the utility, which added expense must be reflected in the rate for service. That is just exactly what commissions are for, and a large majority of commissions have done their work very well indeed. Commissions are not quite 100 percent perfect, just as you and I are not 100 percent perfect, but on the whole commissions in a majority of cases do the right thing, as the experience of the country has shown.

I do not wish to leave with you the impression that public utility companies do not look with favor on the small customer. They realize their obligation to the small customer. It is true that a great many small customers are really a loss to the company, especially where there are only say five customers or less in a block. If the number in such block can be increased sufficiently, they may become a source of profit. For that reason everybody has a direct interest in increasing the density of residence customers.

In closing, I want to say only this, that this is a subject in which every one is individually and collectively interested. The electric utility in its full development is based on a sound economic truth which must prevail, and it will and in most cases does prevail. It is a matter for cooperation, and honest effort to bring about the best ultimate result to all parties interested.

THE RELATION BETWEEN ENGINEERS AND CONTRACTORS

By J. W. ROLLINS*

The engineer and contractor of the present day are both technical men—the one designing the work and then superintending its construction; the other working out the best method for doing the work and then carrying out the actual construction under the direction of the engineer.

This relation has materially changed in the last few years owing to the great development in modern engineering. In the old days when work was done mainly by hand labor the engineer was "boss" in many ways, and the successful contractor was the one who could drive his men to the limit, but who had no technical knowledge and in many cases no education, but was guided by that greatest of all gifts, "common sense." He looked up to the engineer as his superior and expected from him such instruction and direction as was necessary to keep him out of trouble.

Today, however, the situation is entirely changed, and the contractor is often obliged to have more technical knowledge in order to execute work than the engineer who designs it.

It is not a difficult proposition for an engineer to draw a plan showing a foundation for a bridge in water 100 feet deep, possibly in a swift current and in the midst of navigation; or to show a subway 50 feet below heavy buildings in a crowded thoroughfare, under the surface of which may be an electric conduit of 20 000 or 30 000 volts, large water mains under 200 pounds pressure, steam pipes with 500 pounds of live steam, added to sewers, telephone and telegraph lines without number and possibly electric conduits for street car traffic; but to construct such work successfully requires a contractor with great technical skill and knowledge, a man with great resources and strong nerves to meet all the troubles which may arise.

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The writer heard Colonel Goethals of Panama make this statement: "The people think the Panama Canal is a great engineering feat, but it isn't a particularly great work of that kind, but rather a job of handling a great amount of material; and as an engineering proposition the Panama Canal does not compare with the work done on the New York subways."

When the engineer gives out contracts for work of this kind he should have confidence in the contractors who will do the work; and in turn, the contractors should have full confidence in the engineer. That is, to get the best results there must be the heartiest cooperation between the man planning the work and the man doing it.

The medium between the contractor and the engineer is of course the contract and specification, and to these matters I would ask your particular attention.

A contract as defined by John Casson White "is a meeting of the minds of the contracting parties," and with this one definition in mind, I think the engineers and contractors could easily settle their disputes, if they could keep the lawyers out of the case. But they can not, and the result is that most engineering contracts have many clauses which are most unjust to the contractors, who by signing them give up almost their "birthright."

That a contract in its terms should comply with the definition before given, "a meeting of the minds of the contracting parties," its terms should be so plain and explicit—as free as possible from legal verbiage—that any contractor of reasonable intelligence should understand what he is agreeing to do, when he signs the contract.

It should be assumed that when a contract has been awarded, the contractor expects to do the work called for in accord with the terms of the contract and specifications, and to make a profit on his work; that the engineer also expects to have his work done as he has specified, and if so done is willing to have the contractor make his profit. That is, he will do justice to his clients or employers by getting the work done well, and to the contractor in seeing that he is paid justly for what he has done.

The lawyers are responsible for some of the objectionable clauses in contracts, particularly the "blanket" clauses, so called, which hold the contractor responsible for everything that might happen, whether through his fault or negligence or through the fault or negligence of other parties.

There are often many terms and conditions in a contract, of which neither party knows the meaning, and often the lawyers who put in all the blind, blanket clauses make them so blind that their true meaning has to be settled by the courts.

Here is one of those legal clauses which the writer is certain never originated in the brain of an engineer:

"The said contractors hereby declare and agree that they shall be accountable for the full performance of this contract, and by signing hereof admit that the said plans, elevations, sections, specifications and parts before referred to are sufficient for their intended purpose of doing the said work, and that the work can be successfully executed in accordance therewith, without any additional or extra work other than that set forth thereby or necessarily inferred to be done from the general nature and tendency of the plans, drawings and specifications aforesaid, upon a fair and liberal construction thereof."

This apparently innocent clause which at the time was looked upon as one of a lawyer's ideas of a proper contract and was not expected to be understood by the contractors, cost us $10 000, and a railroad company an equal amount.

We agreed to build the masonry for two abutments and a pier for a railroad bridge across a river. The plans showed the two abutments directly behind the old ones with a clearance of about two feet at the foundation lines.

The abutments were 36 feet high and when the excavation got down to the footings it developed that the old masonry projected into the line of the new work, so that a cofferdam could not be driven to get the new foundation in. It so happened that the bridge was in a mill pond, so that by drawing the water off on Sundays we finally got the bottom in.

We also got into trouble with the pier, which was on piles with concrete deposited under water for a foundation. The piles were driven and the concrete deposited, and after a week or so an examination of this concrete showed it had not "set." We waited another week, then a month, and finally tried to pump the cofferdam out, with the result that the bottom "blew up," showing the concrete worthless.

Tests were made of the cement—I think it was "Lehigh." and it was proved to be all right—but in making tests using the river water the samples would simply "slump," and seven different brands showed the same result. Tests of the water showed it to be polluted by mills above the bridge so that the cement was ruined.

We had to drive a 6-inch dam under the bridge girders at an enormous expense, pump the dam out, deposit the concrete in the dry, and then build the pier.

Meanwhile we were discussing with vigor the matter with the engineers—finally at the completion of the work making a claim for extra pay on account of the conditions developed during construction.

Our attorneys, however, called our attention to the clause in the contract above read, whereby we had practically "guaranteed" that the work could be done according to plans and that we would not make any legal claims for variations.

The railroad people were fair in the matter and paid half the loss, which we were glad to get in face of the adverse legal opinion given us by our own counsel. But such a clause, in the opinion of the writer, is an absolutely unjust one.

There are other clauses and conditions for which in the opinion of the writer the engineer is responsible, and which completely nullify the drawings and general specifications and make absolutely indefinite the amount of work to be done.

For instance,—

"Excavations shall be made of dimensions indicated upon plans, where dimensions are given, *or as otherwise directed.*"

"Piles shall not be driven below elevation 102 and shall be cut off at these levels *unless otherwise directed.*"

Also the clause which allows the engineer to make changes in the line, grade, plan, form, dimensions or materials of the work, with no allowance made for extra payment, when conditions vary.

Anyone can readily see what abuse an engineer could make with these clauses where the contract might be for deep water work, as was the contract from which these were taken; thereby compelling the contractor to go to any depth inside cofferdams with his excavation and pile work.

Another clause and one which is also general, disclaims all responsibility of information furnished, and in some cases of quantities of work to be done.

Inasmuch as the Supreme Court of the United States has held that borings shown on plans must be taken as the basis of the contract for such items as are covered by them, it would seem that this decision would be broad enough to cover all information given.

And why shouldn't information given be held as the basis of the contract. The engineer spends months in making plans and estimates and getting information upon which to base them. This information is, in the judgment of the engineer, correct, and on his part is the basis of the contract, and on this information the minds of the contracting parties "meet." It is an impracticability for a contractor to spend the time and money to investigate conditions of a contract as thoroughly as the engineer does, and he doesn't do it, although the contract says he must from his own knowledge make his bid.

So when conditions change, why should not the conditions be met, in a man to man fashion, and paid for in full justice to both parties. This is a vicious clause, one which causes much trouble and which should be eliminated from all contracts.

As to the matter of *guaranteeing quantities:* This is often a difficult matter, for unless investigations are very complete it is almost impossible to make even approximate estimates.

It generally does not hurt a contractor to have quantities *increased,* but may cause trouble to have them materially decreased, for this reason: On some jobs there is a large overhead, general and plant expense, and this expense in an itemized bid must be divided up among the items, and we generally try to add this expense to the items which are fixed or may be increased, but if some of these items are decreased these general expenses will not get paid for.

The writer is of the opinion that where quantities are given, even as "approximate," the courts have held that they must not vary more than 20 percent either way, and if they exceed this variation may be subject to additional payment if this variation causes loss to the contractor.

"The quantities of the various classes of work to be done and materials to be furnished under this contract, which have been estimated as stated in the Information for Bidders attached hereto, are approximate and only for the purpose of comparing, on a uniform basis, the bids offered for the work under this contract, and neither the Commonwealth nor the Directors are to be held responsible if any of the said estimated quantities shall be found not even approximately correct in the construction of the work. The Directors further reserve the right to increase or decrease the quantity, or to omit entirely, any item or portion of the work as they may deem necessary without change of price per unit of quantity, provided that the net increase or decrease of the sum of all said items, as determined by the Engineer's final estimate, does not exceed twenty-five (25) per centum of the total of the original bid."

Here is another such clause:

"The Directors reserve the right to suspend the whole or any part of the work herein contracted to be done, if they shall deem it for the interest of the Commonwealth so to do, without compensation to the Contractor for such suspension, other than extending the time for completing the work as much as it may have been delayed by such suspension."

Two or three years ago we took a contract to build a railroad in New England in an inaccessible country, and spent $300 000 in plant, equipment and in getting it onto the line of work.

About this time came the crash in New England railroads, and we expected to be ordered to stop work. We were not, however, although I think there was a "stop clause" in our contract; and if trouble had come, where do you think we would have "gotten off?"

The idea of mutuality—the meeting of minds—is all forgotten. The intelligent engineer understands the contract, what it means and requires, but in case of dispute the lawyers come in, and the legal lights settle, or try to settle, with no idea of the mutuality.

The Supreme Court of the United States in over-ruling a decision of the Court of Appeals held that misleading boring records are ground for recovery of damages by contractors.

"This item is based on a charge of erroneous and deceptive borings and misrepresentations in the specifications and drawings."

"The specifications provided: 'The material to be excavated as far as known, is shown by borings, drawings of which may be seen at this office, but bidders must inform and satisfy themselves as to the nature of the material.' "

"The material actually to be excavated consisted largely of stumps below the surface of the earth, buried logs, or cemented sand and gravel, none of the sand or gravel being described in the said drawings as cemented, and of sandstone conglomerate: and such materials were far more difficult and expensive to penetrate and excavate than ordinary sand and gravel as described in the drawings."

"The claimants were forced to rely wholly upon the information furnished them, the time not being sufficient to permit them to make their own borings, and they believed the information furnished them to be accurate and reliable."

The opinion of the court in concluding was: "For the error in not allowing the demand for greater expense of excavation and pile driving due to misrepresentation of material in the specifications and drawings, the judgment is *reversed* and case remanded for further proceedings in accordance with this opinion."

There is always much discussion as to clauses which for their execution call for what practically is an impossibility, and as to whether they can be enforced, or compel the contractor to pay the penalty.

A recent opinion of the court on the question of executing an impossibility:

"There can be no question that a party may, by an absolute contract, bind himself to perform things which subsequently become impossible, where the event which caused the impossibility might have been anticipated, and guarded against in the contract, or where the impossibility arises from the act of default of the promisor. * * * But where the event is of such a character that it cannot be reasonably supposed to have been in the contemplation of the contracting parties, when the contract was made, they will not be held bound by general words, which though large enough to include, were not used with reference to the possibility of the particular emergency which afterwards happens."

We have had some sad experiences with this impossibility clause.

On a certain contract for an intake for an electric power development, we had to build a sea wall, and the plans showed 6-inch hard pine sheeting driven to a depth of 20 feet below mean low water.

The specifications said "Sheet piling should be driven as shown on plan," and no borings were taken and no information given as to the material through which the material was to be driven, although the general character of the soil was sand.

This line of sheeting was to act as a permanent bulkhead, and would be of no value if not driven without crippling or deforming the timber.

Before we got ready to begin our work other construction immediately adjoining us was undertaken by driving similar sheeting for a deep trench, though through no great depth of soil, with no success, the timber being badly crippled and broken.

We called these conditions to the attention of the engineer, but with no results, so we began our work, but could not drive the sheeting, though we tried every contrivance known, with heavy water jets and steam hammers.

Finally the engineer admitted we could not drive the sheeting satisfactorily and the plan was changed by dredging out most of the sand and gravel, driving the sheeting and refilling the dredged area.

Before this was done, however, we made the "impossibility" plea, but were told that the company's lawyers wouldn't listen to it, that we had agreed to do the work according to the plans, and that if necessary to get the sheeting down to grade we should bore holes in the gravel or rock if there, and stick the timber in these holes.

Another condition common to contracts, which we object to, is the one under which the engineer can design a structure and give the exact instructions under which the work is done, or require the approval of the engineer to a design submitted by the contractor, and yet disclaim all responsibility for the results. The principles in law on this matter have been pretty well settled by the courts.

A decision of the Supreme Court of the United States has settled the fact that an engineer designing a structure and directing in full the construction, must assume the responsibility for its fulfilment of its functions.

For instance, although a contract states that a contractor must guarantee a waterproofing job, if the engineer prescribes the method of construction and supervises the work as done, this guarantee can not be enforced.

A notable instance of this was developed in the construction of the Charlestown Navy Yard dry dock at Boston.

"The construction of this dry dock required a cofferdam of great strength, although of not very great length; the excavation going down to 40 feet or more below low water."

"The contractors for the work were men skilled in water construction, and submitted a plan of cofferdam to the United States Civil Engineer in charge of the work; and this plan was objected to as lacking in strength, and the plan returned to the contractors. A second plan submitted by the contractors was similar to the first, but showed greater detail; and this plan also was rejected by the engineer and returned to the contractors. The contractors afterwards submitted several other tentative plans for the construction of a cofferdam; but they were disapproved and rejected by the engineer."

"Subsequently the engineer suggested a different plan of his own for the cofferdam, the details of which were worked out by the contractors under the advice and approval of the engineer; and the cofferdam was finally constructed by the contractors substantially according to the plan proposed, under the direction and approval of the Government Engineer in charge. The contractors objected to the plan as proposed by the engineer, but never made any formal protest as to its use. During its construction three breaks occurred, the first two of which occurred because of defects in the plan suggested and directed to be used by the engineer and these defects were such as the exercise of ordinary care and skill in the construction of cofferdams would have foreseen; the third break was owing to causes which could not have been foreseen by either the contractors or the government inspectors in charge. The repairing of these first two breaks cost the contractors the sum of $27 821.08."

"The several breaks in the cofferdam compelled the contractors to keep up the pumping plant and perform pumping in the excavation of the dry dock longer than they otherwise would have done. The first two breaks mentioned compelled the continuance of the pumping plan for 34 days longer than would have been necessary had these breaks not occurred, and the cost of said pumping was $37.20 per day, making $1264.80 for 34 days."

"The specifications which were made a part of the contract provided:"

> "The works included in the contract will be carried out by the contractor under the inspection and supervision of the civil engineer detailed for the purpose, who will inspect all the materials and workmanship and will have full authority to reject any which, in his opinion, are not in full accordance with the true spirit, intention and meaning of the contract, plans and specifications."

"It is true that the contractors by these provisions of the contract agreed to construct the dry dock 'under the inspection and supervision' of the government engineer, and 'subject to his approval'; but we do not think that they thereby agreed to suffer any and all losses which might occur to them by reason of his mistakes in directing the manner in which the work should be done. We certainly do not think that they agreed to bear losses which might occur by reason of defects in a plan proposed and directed by him to be used, which the exercise of ordinary care and skill should have foreseen."

"Numerous cases to the same effect might be cited, and we believe the rule in cases of this character to be that where a contractor constructs a work under a contract which provides that it shall be done under the direction and supervision of an engineer appointed by and under the employ of the owner and loss occurs to such contractor by reason of defects in the plans directed to be followed by such engineer, of a character which ordinary skill would have foreseen, the owner should pay for such loss. Following this rule the loss occasioned by the first two breaks in the cofferdam is allowed to the claimants."

The custom of giving certain information and then disclaiming any responsibility for it, has been settled also by the Supreme Court.

"The United States Government built a dam in Kentucky, stating in the contract: 'The dam is now backed for about 50 feet with broken stone, sawdust and sediment to a height of within 2 or 3 feet of the crest, etc.' Also stating: 'Bidders or their authorized agents are expected to examine the maps and drawings in this office, which are open to their inspection, to visit the locality of the work, and to make their own estimates of the facilities and difficulties attending the execution of the proposed contract, including local conditions, uncertainties of the weather, and all other contingencies.' "

"The sawdust and sediment backing proved to be crib work filled with stone, and a claim was made for extra payment."

The Supreme Court's decision was: "Where the specifications for repair of a dam say that the existing dam is now backed with broken stone, sawdust and sediment, and is actually backed with solid crib work, the Government must pay the increased cost of removal, notwithstanding other provisions in the specifications, notifying bidders to visit the locality, estimate difficulties and obtain information necessary for an intelligent proposal. The contractor has a right to rely on a positive assertion of such a fact without an investigation to prove its falsity."

We contractors do not see why we should have to fight for justice in such cases as these.

We make our proposals on the basis of the information furnished us, and this information is generally the true and best judgment of the engineers who are doing the work. If then conditions develop which neither party ever considered, why in the name of justice and fair play should the contractor have to suffer?

Some of the trouble comes from the fact that the principals in many cases will not allow the engineer to make sufficient investigations to determine with reasonable accuracy the exact conditions.

Another trouble comes from the fact that public authorities do not dare to make a just settlement as against the strict legal interpretation of the conduct, and when it comes to this interpretation it is a legal one and nothing else. Some *legal* decisions, and by our highest court, are so absurd that even we contractors have to smile at their absurdity.

"In 1878 a contract was made for transporting military supplies from the Kansas Pacific Railway to various points, by team, and the contractor was to be paid by mileage of material hauled, the distance to be fixed by the chief quartermaster of the district."

"It was shown in court that some of the distances fixed were less than the air line distance between the points. The Supreme Court ruled that the contractor having agreed to accept the distances as found by the chief quartermaster could not recover, though the distances given by him were proved to be wrong."

"Another contract, for a post office building. The contract provided that if materials were omitted or added there should be a deduction or addition of price at the market rates, these to be determined by the supervising architect of the Treasury Department, his decision to be final."

"The contract specified Vermont marble, but by agreement Tennessee marble was used. The supervising architect made a deduction which the contractor disputed."

"The Court of Claims ruled that there had been no 'omission' or 'addition,' but a 'substitution,' and consequently the contractor was at liberty to show by any available proof the value of the material furnished by him."

A case of finding a flaw in the wording of a contract, which enabled the court to do justice to a contractor:

"The Government contracted with the Cramp Shipbuilding Company to build the battleship 'Indiana,' but caused long delays to the contractor by not furnishing material or armor, for which delays an extension of time was granted."

"The contractors claimed heavy damages, which the Government denied, and opposed the suit on the ground that upon the payment, a release had been executed by the company as required by the contract, forever discharging the United States from all debts and demands whatsoever in law or in equity for or by reason of or on account of the construction of said vessel under the aforesaid contract."

"The Court of Claims ruled, however, that this release did not cover a claim of damages arising out of a *breach* of the contract, the release being of all claims for damages growing out of the *performance* of the contract."

"These cases show in a way how absolutely legal court decisions may be; and smart lawyers may find loopholes in contracts which in getting through them do an injustice to one of the contracting parties, though in one of the above cases it enabled the court to make a decision which was absolutely in the line of justice."

Much trouble comes to contractors and the engineer is often placed in an embarrassing position, when orders are given by the latter for extra work, or contractors are told to go ahead and do the work and he will see that they get paid for it.

In my early work as a contractor we used to go ahead and do anything the engineer asked us to do, with full confidence that we would get paid, and we generally did. It would never do to stop to discuss matters as to extra work, when we had a railroad track up on posts and all trains slowed up to cross on them. We would have been fired off the road for good and forever, if we had taken this course, though probably the contract expressly provided that no extra work should be done without written orders from the chief engineer.

We contractors are willing to give and to take, to do any little thing an engineer wants even if outside the contract: its our policy if we are wise to keep on the good side of the engineer and trust he will return the favor in some way, and for that reason we are reluctant to make a claim for extra work in these cases, as such a claim would not make us popular, and so we fail to comply with the conditions of the contract which require that claims must be made in writing within a week or two after the work is done.

Today, however, the engineers stick so closely to the specifications that they cannot do us any favors, and we have to look over the contract more carefully and comply with all the legal requirements.

To be absolutely safe a contractor should refer all contracts he proposes to bid on to his attorneys, and should have one at his elbow to advise him throughout its continuance.

We got into very serious trouble in building a section of the New York subways from our neglect to safeguard our work in this way.

We asked permission to build a power house in Union Square, and it was given us by the Transit Commission and various other public officials. We built the power house opposite a hotel, the lessee of which promptly sued us for damages. We won in the first court, lost in the second and Supreme Court, and finally paid $98 000 in damages; the court holding that the Transit Commission and others had no authority to give us this permission, but that it should have been asked for and obtained from some other Commission.

We just escaped a more serious loss in another case:

We contracted to build a bridge in Massachusetts costing about $800 000, across a deep river near tide water. The plans were meager, giving no details, simply showing piers on rock bottom 60 feet below water, and on piles 40 feet below water; the contract specifying that the contractor shall submit plans showing the method of constructing the foundations, to the engineer for his approval, and also stating: "the work shall be done as shown on plans," and that changes could be made by the engineer with the approval of the Joint Board of Commissioners.

The plan was merely a sketch showing the piers and abutments outlined, and the work could not have been built in that way. The chief engineer, who by the way was not the engineer who made the contract plans, made up detail plans, showing Pier 4 on piles on a wooden grillage, 40 feet below low water. The work was built according to these detailed plans, was accepted and paid for in full.

A year later Pier 4 settled 15 inches in one jump, and at one time it looked as if the whole bridge was going down.

We were asked to investigate the trouble, and found that the teredo, a water bug, had eaten off the piles in this pier and had allowed the pier to settle onto the river bed, which fortunately was hard material.

Of course, this raised a row, and as the engineer had died, the commission disbanded and the engineering force dismissed, there was no one left to hold responsible but the poor contractors.

We, however, proved an "alibi," as far as actual construction went, but the legal question was brought up, that these plans, particularly of Pier 4, which had settled, had never been approved by the Joint Board; that is, the records of the Board did not show any action whatever on this pier.

We were sued for $300 000, but the case was never tried, and has since been abandoned.

But here, we accepted working plans from the engineer, executed then under his direction and to his satisfaction, finished the bridge, which was accepted and paid for, and yet we were held liable for loss arising later, solely because the engineer did not get his plans approved.

That is, a contractor accepts plans and orders from the engineer, does work according to his plans, all without question, in good faith on both sides, with the belief that the engineer has authority for his plans and orders, and that on his certificate he will be paid for all the work done under it; and yet in a lawsuit the contractor cannot recover if the engineer has exceeded his authority.

So you engineers to protect yourselves and not do unwittingly a great injustice, should protect the contractor, by getting plans and orders approved, when so required by the contract, because most contractors will never ask the question as to your authority.

In a paper presented to the Boston Society of Civil Engineers in 1907 on the subject of engineers' contracts from a contractor's viewpoint, much discussion was brought out, and I quote from one by one of our ablest Boston engineers:

"We have heard an excellent discussion on what a contract should be, how it should be drawn for a fair minded contractor. He has *not* told us what kind of a contract we should draw when we have to deal with an unfair minded contractor It should be remembered that when the contract is drawn the engineer does not know what kind of a contractor is going to get the job. He has got to assume that he will not be a man who will meet him in a fair spirit and therefore he must trust to the contract, and he draws one which will give him the advantage. That is to say, if a controversy is going to ensue, and the very practicable question comes up, who is going to have the whip hand in the contest, of course the engineer will try to secure it for himself." And this gentleman concludes by saying, "If all contractors were fair minded and honorable men, I would agree that these clauses would have been much better left out."

Mr. J. A. L. Waddell, in a lecture to students of technical schools, on engineering controls, in 1905, said on this subject, and most fairly:

"It is advisable to keep constantly in view the possibility that *each* party to the contract may be unscrupulous and willing to take every possible advantage of every weakness which the contract may contain and will tend to his own profit; honor and integrity to the contrary notwithstanding."

"Failure to do this will often result in some ambiguity which will cause rank injustice to one of the parties to this agreement."

These statements from eminent and fair minded men are typical of many expressions of the same kind, to the effect that the engineer must put these objectionable clauses in his contracts to protect himself from the unscrupulous contractor.

Are engineers willing to admit that they cannot take care of themselves and their clients, with the help of their lawyers, in a contest with the contractors, as to facts and conditions?

Let us look at the clauses we object to and see how many of them are put in for this protection, and how many are responsible for most of these disputes and which are unjust and unfair to all contractors.

The list is about as follows:

1. Disclaiming responsibility for soundings and other information as to the character of the work.

2. The insertion of the clause which may make any contractor's estimates and bids worthless—"Or as otherwise directed."

3. Making contractors responsible for work for which the engineers make the plans, or require the approval of the engineer to any made by the contractor for temporary work, and where the engineers reserve the right to entirely control the manner and means of construction.

4. Holding contractors responsible for work which has been built under the direction of the engineer, and passed inspection, unless fraud and gross negligence is proved.

5. Making the engineer the sole referee in settling all claims.

6. The right to stop work or any part of it, if for the interest of the engineer so to do, without allowing the contractor any compensation for such action.

In the opinion of the writer, none of the above objectionable clauses afford any protection to the engineer against a bad contractor, but do hold out a threat and often work a great injustice to a fair contractor.

Most contracts today have a provision to this effect:

"It is the purpose of the Company not to award this contract to any bidder who cannot furnish evidence satisfactory to the Directors that he has ability and experience in this class of work, and has sufficient capital and plant to enable him to prosecute the same successfully and to complete it within the time named in this contract."

Again, you have these standard clauses:

"If at any time the Engineer shall be of the opinion and shall so certify in writing, that the conditions specified as to the rate of progress are not fulfilled, or that the work or any part of it, is unnecessarily or unreasonably delayed, or that the Contractor has violated any of the provisions of this contract, the Company may notify the Contractor to discontinue all work, or any part thereof, and thereupon the Contractor shall discontinue such work or such part thereof as the Company may designate, and the Company may thereupon, by contract or otherwise, as they may determine, complete the work, or such parts thereof, and charge the expense thereof to the Contractor, and may take possession of and use or cause to be used in the completion of the work, any of such material, animals, machinery, implements and tools of every description as may be found upon the site of the work."

These two clauses, in all contracts, and properly so, give the engineer absolute control of the letting of work. First, by not awarding contracts to *low bidders*, who can not absolutely qualify as specified,—in financial ability, experience and plant. Secondly, by using the authority given you by the contract to either take the work away from the contractor or to use the contractor's equipment to finish the work under the direct charge of the engineer.

You ask and require us to comply with the contract—why may not reputable contractors ask that you comply with the requirements of the contract, and throw out low bidders who cannot qualify.

You say you put all the clauses we do not like in contracts to protect you from dishonest and incompetent contractors. We say in answer to this, that these objectionable clauses are not the ones that give you this protection, and that the very ones put into contracts to protect you, and to which we offer no objection, you do not take advantage of.

You will say again, in public lettings, we have to award our contracts to the lowest bidders who can furnish the bond required, that politics will control this, and to save yourselves trouble and annoyance you cannot avoid letting the low bidder get the work.

It is rather remarkable how many influential and public minded citizens will be found ready to plead for some "bum" contractor, and how little interest these same citizens show when the trouble comes to the engineer and financial loss to the city, through failure of this same "bum" contractor to finish his work. Here is a chance for engineers to do good work in civic reform.

It would seem from the decisions of the courts that most of the clauses which the writer has quoted as being onerous and unjust are outside the pale of the laws anyway; so why need they be put in contracts at this enlightened stage of the world's progress? I do not think you engineers are responsible for most of them, and their only accomplishment today is that they furnish a club to scare some poor contractor who, when shown the clauses in his contract, which may be sacred to him as something he has agreed to do, dares not, or cannot afford to fight for his rights, and so compel him to make an unjust, losing settlement of his claims.

But contractors are changing, as has been before stated, and the strong and able men who today are doing the great works, who are willing and ready to fulfill every part of their agreement, are going to demand of the principals for whom they work, a like complete fulfilment of their part of the contract.

City and commission engineers often hold back payments, do not make up their estimates, particularly finals, because, they say, they have not had time or men to do it. How long would they listen to us if we made the same excuse—a lack of time or men in carrying out our work?

Still another clause, almost a universal one in contracts, that providing that the decision of the engineer shall be final and binding on both parties.

It is admitted that the engineer, having made the plans and specifications, knows what he wants for workmanship and material, and his decision on these matters should be final, and it is to be hoped that the specifications are so definite that there can be no question of the material required.

The necessity for a decision does not come up until there are matters in dispute, at which time the engineer has already given his decision against the contractor, so that he is in the position of a judge who decides his case before he hears the evidence.

Engineers generally have made an estimate of their work, and if based upon knowledge carelessly obtained, by incomplete surveys or soundings, it is only natural for them to try to avoid the trouble of explaining discrepancies of their estimates, which are brought to light by claims for extras.

It is also conceivable that engineers are often held closely accountable by their principals in the matter of *costs*, have not been allowed to properly investigate the work to be done, and it is easier for them to hold up the contractor than to make peace with the owners.

We think therefore that when the engineers and contractors cannot agree that the matters in dispute should be settled by arbitration. This clause we believe is in the standard forms of contracts used by architects, and is often now provided for in engineering contracts.

A fair clause to this effect is from J. A. L. Waddell's paper on contracts and specifications:

"The decision of the engineer shall control as to the interpretation of drawings and specifications during the execution of the work under them, but if either party shall consider itself aggrieved by any decision it may require the dispute to be finally and conclusively settled by the decision of arbitrators, each side choosing one, these two a third member, and the decision of the majority to be final and binding on both parties."

Extra work is the *bete noir* of the engineers, and it is not always a circus for the contractors.

Engineers provide for this item in various ways. In some of the large public works in New York they make no provisions for it, and it results in leaving all such claims to a court to settle, after years of waiting, and interest charges accordingly, while most of the items could probably have been settled by the engineers and contractors.

Some engineers think extra work is a clear "bonanza" for the contractor, but let me give you a few inside facts and figures. A very careful cost account on a reservoir job in New England showed a general expense item of 12.9 percent of the whole contract. This general expense included superintendence and miscellaneous general labor, insurance, including bond, freight and teaming plant, general office expense (field work), timekeepers, storekeepers, blacksmiths and watchmen

On five jobs done by us, amounting to three million dollars' worth of work, the general force was 10.1 percent of the payroll.

So we start with the direct cost of work, including labor and material, add to that 10 percent of the payroll for general expense, 5 percent of the payroll for the use of small tools; also a proper charge for wear and tear of heavy plant; and then in the sum of all these you get the actual gross cost to the contractor of *extra work.*

Now you *generous* engineers allow us 15 percent of the actual cost of work, which includes insurance, a proper allowance for superintendent, watchman and timekeeper, and a reasonable rental for large plant. If there is a lot of material used and plant required, extra work may pay the contractor, but if only labor is used, with no plant, the less extra work done the better off we contractors will be.

But the above quoted clause is a generous one and consequently is seldon used, most contracts providing for only 10 percent profit, often not allowing insurance as a cost, and no allowance for tools, superintendence or plant. Under such a clause extra work is done at great loss.

You engineers, some of you, will say, that argument is weak, that we have to pay a superintendent, watchman, etc., anyway, that our plant will be standing idle and may better be used; and so our claim for a proportion of general expense and bills is not well founded. That claim is similar to those sometimes made about railroads—the locomotive and cars are going to make the trip anyway, and it won't cost the railroad company any more to carry a man or two along; but somehow this argument won't work with the conductor, and we either pay or *walk*.

In the opinion of the writer there is no occasion for the general trouble and rows over extra work.

A good contract provides that the contractor must get a written order for extra work, must show his payrolls and vouchers and give all information as to these items, and it only needs a little business sense to get daily reports as to material used, and to daily check up the labor items; and then the disputes cannot get far.

It would seem possible for the engineer to keep as accurate cost of these items as the contractor can, and by getting daily checks on payroll and material, it would not seem possible to have any considerable discussion. The trouble comes generally from not agreeing upon these items as the work is done; and after months, when the facts are forgotten and one party, generally the engineer, has lost his notes, it is difficult to get the true facts up as a basis of settlement.

As a contractor, I must admit that many times extra bills are presented and often paid which are simply extortions.

On large public works there are generally engineers and timekeepers enough to keep track closely of extra work, and if they check up with the contractor all goes well. But the public service corporations and other interests, having no political offices to fill, do not have men enough to check up these items, sometimes not knowing that a contractor considers work "extra," and so there being no check on the contractor, extortionate bills are rendered and a row ensues.

Such cases as these make the trouble,—their fame spreads, and consequently all engineers, public boards and owners, try to avoid extra work.

But it cannot be avoided. No plans or specifications of large contracts can be made definite and complete enough to cover the emergencies which make changes necessary.

So make your contracts explicit in defining just how extra work shall be done; always by written order, so that you may know that the work is considered "extra" by the contractor; what shall be included in the cost, how checked up or accounted for, and how paid for.

Then make a reasonable allowance for profit, and it would seem that under these conditions "extra work" could be disposed of to the satisfaction of both parties.

"Every unnecessary or unfair clause in a specification has its part in limiting competition and in lowering the standard of honesty among contractors. A clause that may be used as a club can be avoided in one of two ways—either by not bidding on work governed by the clause or by using graft to insure that it shall be a dead letter."

As to the question of specifications, there is not much to say. They should also be exact and definite and free from clauses which may be interpreted in two or more ways, as for instance:

"Piles shall not be less than 20 feet in length, 6 inches at tip and 10 inches at butt."

We contractors understand this to mean, that no pile longer than 20 feet nor larger than 10 inches at the butt and 6 inches at the tip can be required; while the writer knows of one case where the engineer required piles of longer lengths, on the theory that all piles must exceed 20 feet in length.

Again, "Stone shall be from one quarry, shall be uniform in color, and shall show no sap or streaks."

This was claimed by a contractor to mean that the stone should be from one quarry, that no *single stone* should show sap or streaks, but should be uniform in color. The engineer claimed that all the stone in the work should be from one quarry and should all be the same color, with no sap or streaks.

In a contract we executed, of about a million dollars, the writer had some serious discussion with the engineers, because they used general clauses in specifications, but when we came to do the work, brought out details of specifications which required special requirements. For instance: "Coarse sharp sand shall be used." Later in the work special requirements as to fineness were wanted. Again, "Cements shall be of a well established brand, shall be subject to rigorous tests of such character as the engineer shall determine." Later a requirement as to chemical analysis was made, requiring cement that did not have exceeding 1½ percent of sulphuric acid. As we had contracted for Lehigh cement, and as it exceeded the sulphuric acid limit, and the price had gone up, we objected, and finally were told to get as near 1½ percent as possible.

Again: "The loam furnished shall be good rich black loam, free from gravel, stones and roots, and shall be satisfactory to the engineer." Later, loam was required which contained 8 or 10 percent vegetable matter.

Should not such difficulties as these be avoided by simply putting in the specifications these special requirements, and trouble avoided later when an attempt is made to read them in?

We contractors ask you to make your specifications definite and exact, and later want you to give us some leeway in enforcing them. We admit you cannot say "about" so much or so many, and yet ask you to interpret the clauses in that way.

It is reasonable to assume that most contractors contract for material in accordance with the specifications, and that the trouble comes to them in the delay of the work in waiting for new stock.

The worst trouble comes from stone. Much of it comes from a distance, is cut special, may come in large lots by vessel, with very difficult land connections, or vice versa. Stone is hard, to cut it properly requires great skill, with many chances for some small accident in breaking a joint or a corner. So when your inspectors condemn a stone because a small corner is gone, a joint a hair too wide, some slight discoloration on the face, a dog hole or a plug hole, and it means shutting down the job on that particular piece of work for two or three weeks to get a new stone, we naturally "kick," and we doubly kick if this stone happens to be out of sight, under ground or water.

Again, take the matter of piles, especially very long ones. In New England, such piles come from the South, Norfolk or thereabout, and come by rail on two or three cars. To replace one or two means a tremendous expense and delay—the cost of the single stick, and the tremendous freight charges for it.

These two items and timber are the cause of most of our troubles, and that often due to irresponsible men who actually cut the stone or the farmers who cut the piles, as neither appreciate the idea of exactness.

All we can ask is reasonable inspection, considering all conditions. If we are building a monument, make us build it good and true, to stand time and weather and the critical inspection of the public eye. If, however, the work is out in the woods, under ground or water, with no particular demands upon it in any way; then, if color is off, a joint too wide, a corner chipped off, please do not add to the great burdens which all contractors always carry, by insisting on all the exact details of the specifications, when these details do not add anything to the true value of the work.

If a contractor, bidding on public works today, ever tries to figure on all the chances which may come up, he never will get any contracts. He has to run the risk, to trust that some things will come his way, enough to balance the things that go against him. He doesn't want to be always kicking, making claims for extras, for small things, in the hope that the engineer will give him the benefit in doubtful cases, and such advantages as the work may offer, enough to offset his little extras. But when he doesn't get any of these benefits, especially if he feels that the engineer is wilfully withholding them, is compelling him to do the work to the exact letter of the specifications, where such exact work is of no value to anyone, when he is, in the common term of the profession, "getting roasted," then comes trouble, claims for extras, kicks and general eruptions.

Do you know what the lack of a square deal means? That the other fellow denied this now great American right has it in his heart to "get even" with the man who denies it to him. and it takes a good Christian and a square man to curb that impulse.

Here we end our plea. It has been deep in my heart for many years to see a closer bond between the engineer and the contractor,—that of cooperation, respect and faith, one in the other.

To give and to take, to do justice on the one hand and good honest work on the other, and settle the difference man to man. Then lawyers will go out of our lives, the courts will be left for trust cases and divorce suits, and the day will come of good-fellowship and regard which should exist between the creators and makers of this modern world—the Engineer and the Contractor.

CORRESPONDENCE

Dr. J. A. L. Waddell:[*] In accepting the invitation of the Engineers' Society of Western Pennsylvania to discuss Mr. Rollins' timely and valuable paper, I do so with pleasure, for the reason that although my work places me on the other side of the professional fence from him, I recognize, nevertheless, that the contractor on engineering work has rights of which he is sometimes deprived through specifications rigidly drawn by the engineer in favor of the client. While a certain one-sidedness in such specifications is unavoidable, they should be so drafted as to protect the contractor in his fundamental rights and permit him the privilege of appeal from the engineer's decisions. Strictly speaking, it is not absolutely necessary that the specifications indicate such a right to appeal, for the law will give the contractor that privilege—possibly, though, only after a hard legal struggle. To prevent such a controversy in the courts, there should be an arbitration clause in every engineering contract. Mr. Rollins refers to the fact that I have such a clause in my standard contract form, and quotes the essence of it and I desire to state that I have been using such a clause in connection with all the construction specifications that I have drawn during the last twenty-five years or more of my practice. In respect to my opinion concerning the necessity for such a clause, permit me to quote the

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following from page 73 of my little book on "Specifications and Contracts:"

> "In respect to provision for settlement of disputes, engineers are somewhat at variance. Some think that the engineer should be the sole arbiter, but I do not believe that such an arrangement is just, savoring, as it does, altogether too much of autocratic rule. I am a firm believer in arbitration for the settlement of all disputes on important matters, and it has for many years been my custom to provide in all construction contracts for such a method of settlement."

And from the same page of that book I quote as follows concerning the applicability and usefulness of the arbitration clause:

> "Notwithstanding the fact that the contract reads that 'By the decision of these three arbitrators, or by that of a majority of them, both parties to this agreement shall be finally bound,' the law has decided that the losing party has still a right to appeal to the courts; consequently, this clause of our form of contract is not binding. Although I have known this for years, I have made no change in the clause, for the reason that at least nine contractors out of ten prefer arbitration to the delays, uncertainties and expense that are inseparable from legal litigation, and I have never heard of a case in which the loser by arbitration appealed to the courts. It would simplify matters if, immediately after an arbitration is agreed upon, each party concerned were to give to the other a bond guaranteeing that he will abide by the decision of the arbitrators."

Mr. Rollins is certainly right about its being advisable to "keep the lawyers out of the case." All engineering work should be handled jointly by the engineers and the contractors, if possible without bringing anyone else in to settle their controversies; and if arbitration has to be resorted to, the arbitrators should consist of other engineers and contractors. If a lawyer is on the board, legal quibbles are likely to receive attention, and the settlement of the questions at issue will tend to drag along indefinitely. Arbitrators should act *at once;* and it ought not to be at all difficult for them to make up their minds about any disputed point, provided that they all desire to be governed solely by the principles of equity and justice, as all good arbitrators certainly should.

About the only use I have ever had for a lawyer (unless the matters at issue were forced into the courts) has been to pass upon the correctness and completeness of the specifications and contracts which I have written and today I find that such a precaution is no longer necessary.

The blanket clauses in contracts to which Mr. Rollins objects, are, in my opinion, an indication of the weakness of the writer thereof; for if he had had the capacity to foresee all the possible or even the probable eventualities likely to arise during the progress of the work, there would have been no need for any such broad, sweeping clauses as those referred to. A truly competent engineer ought to be able to draft a set of specifications and a contract for any piece of work so as to cover in detail every important matter and to provide for all contingencies that are likely to arise during the progress of the entire construction. Concerning this matter of anticipating eventualities, permit me to quote the following from page 70 of my before-mentioned book:

> "No portion of the work of contract writing requires greater experience and ability than the forecasting of all possible eventualities that would materially affect the agreement and the proper provision for what is to be done in the case of each eventuality. All contracts are more or less faulty in this particular, for it would require omniscience to forecast all future happenings; nevertheless, in preparing an important contract one should endeavor to foresee and provide for all possibilities and probabilities. The lawyer or engineer who makes a practice of giving this important matter full consideration in every contract that he writes will soon find himself in demand by capitalists to aid them in making their investments and in consummating their enterprises."

Eventualities, though, should be provided for specifically and in detail—not by sweeping, blanket clauses of such a general nature as to turn the contractor, body and soul, over to the tender mercies of the engineer and his client. On the other hand, though, in order to protect the latter against the wiles of unscrupulous contractors, the engineer has to insert certain stringent clauses in his specifications; but a proper arbitration clause usually removes most of their sting.

Contractors really have themselves to blame for the existence of these stringent clauses, because of the proneness of some of them to take advantage of every weak point or omission in the contract or specifications. An amusing instance of this tendency once occurred in my practice; and as it has never appeared in print, I shall proceed to relate it herewith.

A certain western contractor, who had established a large and lucrative practice and who was noted for his shrewdness, died, and his business was taken over by his widow and some of his associates. The new company took a contract of mine for rebuilding a large number of important bridges, the substructure of only one of which involved pneumatic work—and that on but a single pier. One night, *after that bridge had been finished and paid for,* my resident engineer and I happened to be traveling on a train with two of the partners of the said company, when one of them pulled out of his satchel my specifications, pointed out a slip that I had made by asking a price on "mass of pneumatic pier" instead of "mass of pneumatic crib and caisson," and stated that he was going to put in a claim to the effect that this unit price, which, of course, was the highest one on all the substructure work in the contract, should apply to the shaft as well as to the underwater work of the pier. I told him to go ahead and make his claim, but indicated pretty emphatically what I thought about such conduct and what the result of the attempt would probably be, then my companion and I went back to our seat. As I sat down I gave an exaggerated shiver and remarked, "S——, I have a peculiarly uncanny feeling tonight," and when he asked, "What is the matter?" I replied "I believe that T's ghost is with us on the train."

Some contractors are so chronically cantankerous that they make a point of fighting, either on principle or from sheer cussedness, against many of the most important points of the engineer's specifications. One of them who used to work for me many years ago (by the way, he was a red-headed Irishman who would rather fight than eat) carried this practice so far as actually to begin to dispute with me about the legality of my specifications *before the contract was awarded.*

It is such men as those who make it necessary for the engineer to insert stringent clauses in his specifications.

Mr. Rollins objects to the standard clause that allows the engineer to make changes in the plans during construction. Such a clause is a necessity. My standard one reads thus:

"The engineers shall have the power to vary, extend, increase or diminish the quantity of the work, or to dispense with a portion thereof during its progress without impairing the contract; and no allowance will be made the contractor except for the work actually done. In case any change involves the execution of work of a class not herein provided for, the contractor shall perform the same and shall be paid the actual cost thereof plus the percentage for profit agreed upon in the contract. In such cases the engineers will first give a written order, and the contractor must furnish them with satisfactory vouchers for all labor and materials expended on the work."

In the respect to the question of extension of time for completion of contract, I provide further on as follows:

"If, in the opinion of the engineers, the contractor be delayed by circumstances that are absolutely beyond his control, the engineers may grant him an extension of time for the completion of his contract, but the determination of the amount thereof is to be left entirely to the said engineers. In such a case the liquidated damages and the bonus are to be computed from the extended date instead of the date originally specified for completion."

While still dealing with the subject of adequate specifications, if it be proper, I should like to call attention to Chapter LXXIX of my forthcoming book on *"Bridge Engineering."* That chapter is entitled "General Specifications Governing the Manufacture and Erection of the Superstructure, Substructure, Approaches, and all Accessory Work of Bridges, Trestles, Viaducts, and Elevated Railroads." It is something entirely new in specification writing, and the fundamental idea involved could advantageously be adopted by specialists in all lines of engineering work. Briefly stated, the peculiar feature of these specifications is that they cover every clause that is likely to be needed in drafting the specifications for any projected bridge of any kind whatsoever, including all the possible accessory works, such as "pier protection," "shore protection," "fire protection," "operating machinery," "embankments," "pavements of all kinds likely to be used on any bridge or its approaches," "carrying of water pipes or other pipes," "trolley line," "culverts," "houses," "interlocking apparatus," "lighting," "signals," "maintenance of sewers and pipes," "mattresses," "pile dykes," "smoke protection," "remodeling of old structure," "removal of old structure," "stairways," and "temporary bridge."

There are three types of clauses particularized, viz,. variable, incomplete, and permanent; and each clause is marked on the margin correspondingly using one of the capital letters *"V,"* *"I,"* or *"P."* Under the heading "Variable"' there is given a general description of what the clause should contain; and this is followed by an actual example taken from my practice. With this information and having in mind all the conditions governing the new clause, it is an easy task to write it. The incomplete clauses require only certain blank spaces to be filled so as to make them complete; and, of course, the permanent clauses are to be copied without change.

The arrangement of the various clauses is made on a logical basis, primarily chronologically. To apply this specification form to any particular case, the writer of the required specifications takes the chapter and runs down the list, writing the new clauses, filling out the incomplete ones, copying the permanent ones, and, of course, omitting all those that do not apply or which are not really needed. The result is a specification arranged in logical order and with nothing of any importance omitted. I truly believe that the method just described marks the acme of systemization in specification writing.

Mr. Rollins is correct in his views concerning the responsibility for information furnished in specifications. It should rest upon the company or client and not upon the contractor? Concerning this point, I beg to quote as follows from page 8 of my "Specifications and Contracts:"

> "A specification should never hide from the contractor difficulties that are likely to be encountered. On the contrary, when such difficulties are known to the engineer, they should be specially called to the contractor's notice, so that he may bid more intelligently. His attention, however, should not be drawn to them in such a way as to frighten him and to cause him to make a bid abnormally high, but the facts as they exist and are known to the engineer should be stated. As in all relations in life, straightforward, fair-and-square dealing is by far the best policy."

In times past I have been sharply called to task by clients for giving bidders too much information and for causing the said clients to assume the responsibility for the correctness of superfluous data furnished. The criticism, of course, was based upon a pseudo-economic idea, which I always took pains to correct in my clients' minds by stating that the more information the specifications provide (assuming, of course, that the same is correct) the lower will be the prices tendered; and that even if unfavorable facts were withheld, nothing would really be gained, because the contractor would be likely to attempt to scamp his work, or else he would make an appeal to the courts for extra compensation on account of the information furnished being either incorrect or too meager.

The limit of 20 percent variation for "approximate" quantities of materials appears to me to be most liberal. I should certainly consider that a much smaller variation under certain conditions would establish a sound reason for the demand for an adjustment of unit prices. On various occasions in my practice, when the quantities of materials were reduced materially below the estimate given in the specifications, I have allowed the contractor extra compensation to offset his proportionately increased over-head charges.

In respect to the client's right to suspend the work without any increase of compensation therefor, there is no equity or justice whatsoever in such a proceeding; and the courts would probably side with a contractor who claims extra pay for the loss of time and money involved by any cessation of activity ordered by the client, any clause of the contract to the contrary notwithstanding.

I am of the opinion that if a contractor objects to any design or portion of a design furnished him by the engineer, he should do so formally in writing; and that unless he does this, he should not be allowed for his work any extra compensation that is based on the plea that he objected to the said plans.

Mr. Rollins has struck the key-note for most of the unanticipated difficulties in construction when he says:

"Much of the trouble comes from the fact that the principals in many cases will not allow the engineer to make sufficient investigations to determine with reasonable accuracy the exact conditions." It is strange how short-sighted most promoters and even high railroad officials are in respect to this important matter. I often have to tell them that each dollar spent on preliminary investigation means ten dollars saved in one way or another on the cost of the work.

A contractor certainly has the right to request—nay demand —of the engineer a written order for any extra work that he is instructed to do; and no engineer should feel offended when the contractor insists on exercising this right. Such a record would certainly be necessary in the event of the death of the engineer—and what so uncertain a thing is there as life—especially on some kinds of engineering construction!

The ordinary clause in first-class engineering specifications requiring low bidders to give evidence of their ability to do the work is certainly a necessity, and should be lived up to. If it be in either the specifications or the invitation to tender, it assuredly is the privilege of any bidder after the tenders are opened to request the engineer or the client to investigate, before the award is made, the record and the standing of the low bidder and see that the same comply with the requirements of the specifications. Again, I see nothing improper in any bidder furnishing evidence to the effect that the low bidder is not properly qualified to do the contemplated work. My latest clause covering this matter, as given in the before-mentioned specifications of my forthcoming book on "Bridge Engineering" reads thus:

> "At the time of opening of bids any or all bidders may be required to give satisfactory evidence that they have had actual experience in the class of work for which they have tendered. Bids of inexperienced persons or companies and of those bidders who have failed in the past properly to perform other contracts may be rejected for such cause. Each bidder on substructure or erection of superstructure shall submit with his tender a full statement of the equipment he has available for use on the work for which he tenders."

No man who is worthy of being termed an engineer should make a practice of delaying contractors' estimates, because such action cannot be justified on any legitimate plea. An occasional delay of two or three days may be unavoidable, and hence should be pardoned; but a chronic habit of dilatoriness in preparing monthly or final estimates is unpardonable.

Mr. Rollins is right in his statement that the overhead charges on extra work amount to ten percent of the total cost thereof. For some years it has been my practice to allow the contractor for all extra work the actual cash cost to him for materials delivered at the site and for the labor involved in putting them into place plus 20 percent thereof; and I assume that one-half of that percentage would be net profit. In order to avoid the use of the objectionable word "extra" which often acts on a client like a red rag does on a bull, I have headed this item of my specifications, "Unclassified Work." The clause covering it reads as follows:

> "The engineers shall have the right to require the contractor to perform work or supply materials of any class not provided for in the specifications, to be known as 'Unclassified Work.' In case such work or materials are ordered, they shall be paid for on the basis of actual cost to the contractor of the materials and applied labor, plus 20 percent for his profit, no indirect expense of any kind being included. In case complete articles or products ready for installation are furnished by the contractor instead of the constituent materials, the contractor will be allowed for his profit ten percent on the cost to him of such articles. No allowance will be made for superintendence, insurance or any other indirect expense, or for the use of tools or appliances. Satisfactory vouchers will be required from the contractor for all expenses of unclassified work. No payment for any such work will be allowed unless it was ordered in writing by the engineers before execution."

In my opinion, ten percent is enough to allow for overhead charges and a like amount should suffice for profit, in view of the fact that under these conditions there is no possible risk of loss. I am firmly of the opinion that it is much better to base extra payments on actual cost of materials and labor alone, allowing a high percentage for gross profit, than upon the cost of the same plus that of a lot of indefinitely determined overhead expenses, with a lower percentage for net profit. Those engineers who have had to wade through contractors' voluminous and often badly kept records in order to determine the correct amount to allow for overhead expenses will certainly endorse this statement.

Mr. Rollins is right when he says that "Every unnecessary or unfair clause in a specification has its part in limiting competition and in lowering the standard of honesty among contractors." Certainly this statement is correct in so far as it applies to "unfair" clauses, and it is right, too, in reference to those which are truly "unnecessary." But it is a matter of opinion as to what is necessary in a specification and what is not. The old idea that a good specification for engineering work should contain only broad, general clauses without going into details is absolutely and fundamentally wrong because the more detailed the specification and the more ground covered therein the better it is not only for the client but also for the contractor. The longer an engineer practices his profession the longer and the more detailed become his specifications, provided, of course, that he be of the right stamp, and that he is willing to take every precaution to guard his clients' interests, irrespective of the amount of personal labor and effort thereby entailed. My specifications on bridgework of late years have attained the dimensions and completeness of treatises, involving sometimes as much as one hundred large printed pages, including a clause index;—for instance the specifications I wrote for the construction of ten bridges in British Columbia over the Fraser, Thompson, and North Thompson rivers on the line of the Canadian Northern Pacific Railway contain between 35 000 and 40 000 words.

In conclusion, I desire to express my hearty approval of Mr. Rollins' paper as a whole, and especially to endorse his concluding words expressing a wish for a closer bond between the engineer and the contractor—a bond of cooperation, respect, and faith, one in the other—and the exclusion of lawyers from their joint business affairs.

DISCUSSION

Mr. W. C. Hawley: The excellent paper which Mr. Rollins has presented places within the reach of the engineer who is called upon to prepare a contract and specifications or to look after the carrying out of a contract for engineering construction, a valuable fund of information. The engineer can prepare his specifications but his troubles begin when he comes to the contract. He cannot turn that over to the lawyer entirely for the lawyer is not familiar with the technical and practical details of construction. The engineer is forced therefore, to have a fair working knowledge of the

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law of contracts but he should in all cases submit the contract which he has prepared to his lawyer for review and correction.

The speaker agrees with Mr. Rollins that all specifications should be plain and explicit. This demands of course that full and complete information should be given as to all conditions under which the contract must be executed, and altho the obtaining of such complete information may be expensive to the engineer's employer, it will in the end prove to be economy. The contractor who bids on a piece of contract work must provide against contingencies, and the greater the possible contingencies due to inadequate information, the larger must be the sum added for contingencies.

There should always be a reasonable spirit of give and take between the engineer and the contractor. Exact conditions cannot always be foreseen even with a reasonable expenditure for preliminary investigation. Many times it would be foolish to carry out the letter of the specifications when actual conditions are known, and again many times it is necessary to go a little beyond. If the engineer is in a position to give the contractor the advantage in those cases where it is not necessary to carry out the letter of the plans and specifications, he can reasonably expect and will generally find the contractor ready to reciprocate when it is necessary, and in such a case there is saved the cost of such additional work as the contractor does as an offset. In this respect the engineer for a private corporation has the advantage over the engineer doing work for a municipality, county or state. The latter seems to be assumed by our legislators,—at least judging from some of the laws under which he is compelled to work,—to be dishonest and if he is known to vary to the slightest extent from the letter of the plans, specifications and contract, he opens himself to attack by any one wishing to make trouble.

The municipal engineer is further hampered by the legal requirements, which vary somewhat however in the different States, but are to the effect that the contract when let must be let to the "lowest and best bidder' or to the "lowest responsible bidder." Again our law makers have taken the position that neither the engineer nor the responsible municipal officials are to be trusted to let a contract. The low bidder is not as a rule the best bidder, in fact in many cases he is the worst bidder. Many times he is irresponsible, frequently he is a man who has had so little experience that he does not know how to bid nor how to do the work if the contract is awarded to him. The contractor is entitled to a reasonable profit upon the work which he does, and if in progress of the work he finds that he is losing money the work is almost certain to be slighted or delayed and it generally proves in the end more expensive than if the contract had been let to an intelligent, competent, experienced, honest contractor who expects to do the work as it should be done and to be paid a reasonable price therefor. There should be some way provided by which bids that are unreasonably low could be rejected without compelling readvertising of the contract, or making possible the delay of the work thru legal proceedings. Here again the private corporation has a great advantage over the municipal corporation, for it does not need to advertise but can ask for bids from a number of reputable and experienced contractors and can eliminate the undesirable bidder or a bid which it deems unreasonably low.

The speaker agrees with all that Mr. Rollins has said regarding the lawyers. The trouble with the lawyer is generally that most propositions which are submitted to them are viewed as cases to be won, somehow, rather than as problems to be solved. Years ago our Courts were held in high respect. Today they are frequently criticized on the platform and in the press, and we hear much not only of the recall of judges but of judicial decisions. While this attitude is doubtless partly due to the socialistic tendencies of the present time, back of it all there is the realization of the people that many of our legal decisions are unjust. An ounce of technicality or precedent outweighs a ton of equity and right. May we not hope that in due time this will be corrected and that the typical figure of Justice will be changed by the removal of the blind fold from her eyes so that she can see what she is doing and be sure that some lawyer is not monkeying with the scales.

The speaker cannot agree with Mr. Rollins that the engineer should overlook work which does not come up to the specifications. There is of course a reasonble line of enforcement of specifications and as stated above, there should be a spirit of give and take between the engineer and the contractor, but when the engineer and his client have decided upon the class of work which is to be put into the structure, have specified it and agreed to pay for it, and when the contractor has agreed to build it and named a price therefor, the contractor has no right to expect that the engineer will deviate from a reasonable enforcement of the specifications.

The speaker cannot agree with Mr. Rollins in his interpretation of specification for piles. "Piles shall not be less than 20 feet in length, 6 inches at tip and 10 inches at butt." "Not less than" surely cannot be interpreted as a maximum requirement. Obviously the dimensions of the piles must be equal to or greater than the dimensions specified.

Much difficulty would be avoided if the contractor before bidding would study the specifications. He generally checks over the drawings, takes off the quantities and all of that sort of thing, but not infrequently he fails to read the specifications carefully and later finds that they call for better material or a better class of workmanship than those on which he has estimated. Such a contractor has only himself to blame, but the friction and trouble caused in such cases have to be shared by the engineer.

MR. G. W. SNYDER:* I have been on both sides of the fence on this subject, having been in the Maintenance of Way Department of the Pennsylvania Railroad ever since I was a boy, and a large number of the jobs I have had charge of have been carried out by our own forces, so that I was in the position of a contractor. It occurs to me that those who are called engineers and contractors in this paper are analogous to physicians and surgeons in another profession. The physician looks over a patient and concludes that he needs an operation and he calls in a surgeon to perform it. The engineer looks over the situation and concludes that his client needs certain remedies, and the engineer-contractor is called in. If we carry the analogy through, noting the complete harmony between the physician and the surgeon, and imagine such a complete harmony between the engineer and the contractor—it is time to stop for a moment when thinking of this

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complete harmony and consider the owner or the patient for a moment. What is going to happen to him?

It seems to me we can not make any general comparison between the difficulties of designing the work and the difficulties of carrying it out. In one case the engineer has the harder job, and in another case the contractor has the harder job. There is one thing that must be borne in mind in considering this subject and that is that contracts are not made between engineers and contractors but between owners and contractors. Engineers are arbitrators, or judges, they support judgment and love mercy between the two, and therefore it does not seem unnatural that the engineer should be named as arbitrator to decide what is justice. Perhaps the language in most forms of contract, giving the engineer plenary authority to pronounce judgment is rather sweeping. I doubt very much whether, as a practical fact, this produces much trouble. So far as the Pennsylvania Railroad is concerned I do not recall in nearly thirty years' experience ever having heard of a lawsuit to adjust our difficulties with our contractors. That is a last resort. Where a large number of men of different characteristics are engaged in the same sort of occupation, of course sooner or later they will quarrel. But as I once remarked the ideal of the lawyer ought to be professional suicide, in that we should be wise enough and good enough to get along without him.

The language of contracts is no doubt largely made up by lawyers. But in deprecating that sort of thing you must not forget that lawyers put in those clauses to protect their clients in case the matters do get before the courts. The idea of the Pennsylvania Railroad so far as I know is that they shall not get before the courts. I am not sure whether we have any very bad provisions in our contract. Some of them strike me from time to time as rather sweeping.

It is hardly practicable to so thoroughly investigate a job before starting work that the quantities, sometimes even the character of the work, can be ascertained except within a reasonable approximation. Mr. Dravo, for example, in 1903 built a freight station at Irwin under my direction. It was designed in a passenger car from the rear end of the train, and when we got down on the ground to dig we found that we were on a pile of coal gob and had to go down 30 ft. for a foundation, which added considerably more to the cost. The plan called for footings three or four feet below the surface; but we went down 30 ft. and got it settled without the aid of our legal luminaries.

If any changes in the contract or in the plans or specifications are necessary which affect the cost, as is indicated by the original drawings, it is only a matter of common fairness to make settlement accordingly. Our standard specifications in that regard set forth that the Company reserves the right to make any changes in the plans and specifications that it may deem desirable without notice to the surety company furnishing the contract bond. Should any additional labor or material be involved in such changes, the contractor shall be paid for supplying the same. On the other hand, should any such changes reduce the amount of labor or material in the said work as estimated, the contractor shall sustain an equivalent reduction in his contract amount, such changes in the method of doing the work and compensation therefor being arranged for in writing at the time the changes are ordered. In practice I believe that takes care of the situation.

We have another clause in the contract to the effect that if the work is held up or stopped the contractor is to be reimbursed for the labor or materials expended and for the plant made idle, which seems to be reasonable. But sometimes claims are made when work is held up for loss of profit, which we do not generally allow.

A very important part of the paper are the remarks upon having the specifications perfectly clear. There is too much of a tendency in contracts to specify not only the results to be attained but how they shall be achieved. In drawing up contracts and specifications the thing to be set down is the results which are to be attained and the contractors should be asked generally to furnish the methods. The paper for instance speaks about a dispute regarding the design of a coffer dam. I take it the government was not in the least interested in the design of that coffer dam. What they were interested in was what was inside of that coffer dam. As I see it the things inside the coffer dam should have been carefully covered by the specifications and the details of the design should have been left to the contractor without interference from the engineer at all.

The paper contains a great many illustrations of cases in which the contractors were rather hardly used. Well I might give you a few cases where perhaps the boot was on the other foot. I think my first contract for steam shovel work was made before I knew anything about the cost of steam shovel work, and I took a fellow up that I knew had a steam shovel and that I knew was all right and asked him what he would take out the stuff for. No time limit. He said "What is your estimate?" I said, "Well, I can afford to pay 30c." My estimate was 35c. "Well," he said, "I will do it for 30c." As I did not know much about the cost of steam shovel work I was frequently around the work while it was going on and I eventually figured out that he could have done it for 15c and make a neat profit.

There was another case that I was not personally concerned in that is a classic on the Pennsylvania Railroad. An engineer who had spent all his life in the country was suddenly transferred to a large city. One of the first jobs he found himself confronted with was one which required an embankment of 75 000 yards. I do not know how he did it but he had the contract to make that embankment and fill that hole at I think 60c a yard. The contractor put up a big fence around the edge and established an 8 by 10 office with a clerk and a sign "Dumping ground, 25c a load." He collected 60c from the railroad company and 25c from the fellow that filled the hole.

A few years ago we had occasion to remove the old stock yards at East Liberty. We took five or six bids and my recollection is that these five or six gentlemen offered to remove all that lumber from our premises provided they got the lumber and we paid about $5000 to the lowest and $10 000 to the highest bidder. There was a lot of good lumber out there and I rejected all bids. We had our fence up and I put a couple of carpenters and clerks at the gates and advertised lumber at 25c a load. We got rid of the lumber and took in about $4000 in cash. I do not know whether the contractors thought we were easy or whether they miscalculated what was going to happen, but that is what happened.

Another case we had a passenger station built in East Pittsburgh some ten years ago. We asked for bids from a dozen people and those bids ran from $18 000 or $19 000 up to $27 000 or $28 000. We concluded to do the work ourselves and it cost us less than $15 000.

These illustrations will suffice to show that the engineer in his duty to do justice must be on his guard against the hunger of contractors for profits.

Regarding the suggestion that contractors should submit proposed contracts to their lawyers, an engineer-contractor friend of mine remarks that if they did they would never sign any of the contracts the owners were willing to make.

Another point which is not mentioned in the paper is that municipalities and public service corporations must make contracts which meet the approval of Public Service Commissions and their own auditors. We had a case not long ago where our division superintendent made a contract and he and the contractor agreed entirely as to the meaning of a portion of the contract, but the auditor was inclined to question their harmonious interpretation. Of course, we informed the auditor that when the parties making the contract agreed on its meaning, there was no room for further discussion.

Contracts by municipal or political bodies are frequently drawn with the idea of avoiding responsibility if anything goes wrong. For example, the municipal authorities of the City of Pittsburgh rarely make an amicable purchase of property, presumably for fear that such purchase would expose the municipal officers to criticism on account of the price paid. They are disposed to exercise the right of eminent domain, thereby avoiding such criticism of themselves. No doubt, similar considerations affect contracts to perform work.

If I have the correct view of the function of the engineer, it is appropriate enough that he should be named as arbitrator between the owner and the contractor, and that his decision should be final. Where the contractor is so dissatisfied with his decision that he feels further proceedings to be necessary a resort to arbitration is our practice, but we could not favor inserting such a provision in the original contract as it would nullify any weight to be attached to the engineer's decision and lead to innumerable arbitrations.

The remarks as to extra work seem in general very just. However, it is difficult for us to understand why extra work should not all be ordered in writing. True, the original order might be verbal, but there is no reason why the verbal instructions should not at once be followed by written instructions. With our organization this is absolutely necessary, as copies of the orders and acceptances are required to be filed with our Accounting Department.

There is room for great improvement in the quality and capacity of the inspectors. On a good deal of work done by contract these inspectors are often young fellows just out of school who really know little or nothing about the quality of work or of material. Many of them make no effort to distinguish between defects that are of no importance and defects that are of some real consequence. For example, we have a standard track gauge. It has two dimensions where exactness is necessary, namely, the gauge of track 4 feet 8½ inches, and the guard rail distance, 4 feet, 6¾ inches. A number of other dimensions are necessarily shown on the plan. I have heard of a case where an inspector insisted upon calipering every one of these dimensions, involving a lot of machine work of the castings at the ends of the gauge, which was an absolute economic waste. It is fatal to leave the determination of foundation depths to young fellows just out of school. Where that is the practice, it is not uncommon, in the case of branches which have been built of our railroad for us to have to rebuild half the bridge abutments within a few years on account of inadequate depths.

We endeavor to protect ourselves against irresponsible contractors by not asking or permitting such persons to bid on our work. Adequate precautions of this kind seem to me to be better than to allow any one to make a bid and then throw out perhaps the low bids on the ground that the bidders are not responsible. If all the bidders are competent and responsible, there seems to be little or no reason why the lowest bidder should not get the work.

Personally, I do not believe that contracts should be awarded at prices which the engineer knows will bring about a loss to the contractor. The owner has no right to expect anything better than to pay a fair price for his construction, which price should include a reasonable profit to the contractor.

It seems to me that the paper calls attention clearly to the impropriety of inserting unnecessary, unreasonable and oppressive conditions in contracts, but a still deeper lesson is that the function of the engineer is to bring about justice and fair-play as between the owner and the contractor.

MR. L. J. AFFELDER:* The author deserves our sincere thanks for his comprehensive treatment of this subject, important alike to engineers, owners and contractors. I should like to emphasize a few of his remarks by viewing them from a somewhat different angle.

In the first place, let me call attention to the so-called *Uniform Contract,* which is inscribed as follows: "Form of contract adopted and recommended for general use, etc." While certain clauses therein contained may be necessary to a well-balanced contract, how is it possible that a contract can be "a meeting of minds," that is, an agreement to do a *specific* work in a *specific* manner, if it be an instrument of a *general* character?

The uniform contract, as its phraseology indicates, is intended for contracts between owners and contractors, yet many contractors insist that sub-contractors and material men sign the same form. Other printed forms are in use. Architects, engineers and contractors have had attorneys draw up forms which they try to use generally; the general contractor agreeing to construct an office building upon the same form and under the same conditions as the man who delivers a carload of material on a railroad siding and who never sees the site of the structure.

What I want to urge is the elimination of *uniform* and *general* forms and the adoption of *specific* forms, a form for every kind of material or labor. For instance, it is the practice of the company I represent to use one form for erected work and a different form for material delivered only. Too often the engineer who submits a *uniform* form explains when objection is raised to one clause or another: "Oh, that does not apply to your case, and there is no reason why it should not remain." No word should be written in a contract that does not have a bearing, and if left in may lead to wrangling and possibly to a lawsuit. Briefly, let me point out some specific objections to the uniform contract, aside from this general criticism.

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Article VII, for instance, providing for delays which the owner, engineer or others may cause the contractor, requires that the contractor give notice in writing of the occurrence of such delay within forty-eight hours. This is not generally possible; in fact, a contractor who would comply literally with such a condition would in many instances be kept busier sending notices than actually executing the work under contract. Then again the engineer after writing such a clause in the contract complains when the contractor sends him notices. I have knowledge of a penalty and bonus contract which contained such a clause, the engineer's plans were not completed as agreed, and notice was served by the contractor, whereupon the engineer became quite indignant and complained to the contractor that he was too technical. A bonus and penalty contract itself is a technical instrument, and, coupled with a forty-eight hour clause, or, in fact, any clause requiring the contractor to give notice of delays, makes for much unpleasantness between contractor and engineer. Contracts should provide for automatic extension of time equitable to both parties.

In the same clause there is an even greater injustice to the contractor: "The time fixed for the completion of the work shall be extended for a period equivalent to the time lost, etc." Let us suppose the delay throws the work into the winter months, and it is of such a nature that it cannot be done in cold weather. In such case an equivalent extension of time is not sufficient. If the contract covers structural steel, and rollings which occur at long intervals are missed, two days lost may mean two months' delay in securing material. The bridge shop, too, may be required to take up other work to keep its men and machinery going, and this work must be completed before returning to the work which has been stopped. And so, with every trade, examples can be given which prove that the words "at least" should be added to this clause, so that it will read: "The time shall be extended for a period *at least* equivalent to the time lost, etc." This may satisfactorily provide for the time in which the work is to be done, but by no means does it protect the contractor against loss of money due to the delay. Contracts usually provide for damages so caused. but it is difficult to prove them.

Possibly the cause of greatest discord between owners and engineers on the one side, and contractors on the other, is the practice of obtaining prices, closing contracts and starting work before the owner has a fair idea of the construction contemplated or its ultimate cost. Too many changes are made in plans after work has been started. This leads to many unnecessary clashes between contracting parties, loss to the contractor and delay to the owner. I will not take time to discuss the causes of such conditions,—they are many, and the engineer can prevent much of the trouble by encouraging owners to make haste more slowly.

There is a mistaken impression that the contractor usually makes his profits out of extras, whereas the contrary is only too true. Changes and delays do not go hand in hand with profit. A contract to be profitable must be handled expeditiously, but it cannot be properly expedited unless the information the engineer furnishes is exact.

A frequent cause for just complaint is the insistence of engineers that a schedule of unit prices be appended to a contract to cover changes. The cost of changing detail drawings, for instance, may be as much whether material be added or omitted, and for other reasons it is unfair to anticipate the effect of changes.

Specifications are very often incomplete or vague, and it is difficult to determine what is included under a contract. This may lead to much trouble, particularly when there are many sub-contractors, a number of whom could furnish the materials and perform the work.

The troubles of a sub-contractor are the same as a general contractor's, although often they are very much greater, owing to his being farther removed from the engineer. Much could be written on this branch of contracting, but it can best be summarized by repeating the story of the hardships of the Pilgrims.

I believe it was Mr. Choate who said that he fully appreciated the difficulties of the Pilgrim Fathers, but his sympathies were with the Pilgrim Mothers. They suffered the same hardships, and in addition had to put up with the Pilgrim Fathers. Fortunately, however, this is not generally true. Many engineers design and specify clearly and handle their affairs in a business-like manner. We hope there will be more papers like that read tonight, and that practical commercial questions will be given a more prominent part on the programs of engineering societies.

MR. HENRY S. PRICHARD:* The author, in making his earnest plea for fair treatment of contractors, evidently has the advantage of extensive knowledge and experience. The injustices of many of the practices of which he complains will be recognized by contractors, engineers who represent them, and, let us hope, by some engineers and even lawyers who represent the contractees.

The objections to the making the engineer the sole referee in settling all claims and to the compelling of the contractor to not only follow without recourse the instructions of the engineer, but to be responsible for the consequences of such instructions, are objections especially well taken. Many of the other contractual requirements objected to are frequently unjust, but, nevertheless, should not be altogether banned.

The great development in modern construction has, as the author points out, produced a condition of affairs in which the contractor is often obliged to have more technical knowledge, in order to execute the work, than the engineer who designed it. The technical knowledge, even when it consists in the application by mathematical reasoning of fundamental scientific principles to a new problem, is frequently first acquired and promulgated by the contractor or his engineer, as it is he who is most liable to first encounter the new problem. The specialists frequently, perhaps mostly, get their experience and much of their special knowledge as contractors, or in the service of contractors, and subsequently find a better market for their services as contractors or contractors' assistants than as engineers for the contractees. Such being the case it is but natural that in many instances the engineer whose clients desire some large and difficult construction should not attempt with his own limited knowledge and experience to give complete instructions and directions, as in the old days to which the author refers, but should, instead, shift the responsibility for methods and means and risks and successful performance to the shoulders of some contractor who has great technical skill and knowledge and is a man with great resources to meet all the troubles which may arise. Such a contractor, if he is a good business man, will, on an average in the long run, receive ample compensation for all his skill, knowledge, trouble and risk, while the engineer's clients, if they employ an able lawyer to draw the contracts, will have the advantage of knowing in advance of construction just what the enterprises on which they are embarking will cost. Is not this better, in many cases, for all concerned than to have the engineer with inferior knowledge and experience attempt to "boss" the job in all its details?

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Although the writer considers that it often makes for true economy and that it is often to the interest of all parties to have the contractor make his own investigation of conditions and difficulties and assume the risks, he desires it to be understood that he does not condone the giving of misleading information to prospective bidders; and he notes with satisfaction the court decisions which the author quotes showing that in some cases the contractee has not been able, by inserting general clauses in the contract, to evade responsibility for misleading information furnished.

In general, the legal decisions cited by the author tend to create respect for the intelligence and fairness of the courts, not excepting even the ruling of the Supreme Court "That the contractor having agreed to accept the distances as found by the chief quartermaster could not recover, though the distance given by him proved to be wrong." If, in preference to incurring the trouble, expenses and delay of having precise measurements made for the specific purpose of fixing the compensation to be given under the contract, the parties thereto agreed to accept such information as to distances as the quartermaster possessed, a fair-minded arbitrator, be he judge or layman, would decide in favor of the quartermaster's distances in preference to precise measurements subsequently ascertained or discovered, unless these distances were fraudulent or, as a whole, grossly in error. The contractor may have been unwise in entering into such an agreement, but that was not in the issue.

It is not so much against his own folly or willingness to take chances that the responsible contractor needs protection; it is rather against the irresponsible contractor who, without experience, reputation or resources, is awarded contracts simply because he is the lowest bidder. The bond which such a contractor is required to give does not make up for his deficiencies or wholly protect the contractee against them. It frequently, perhaps nearly always, happens that it is necessary to make some slight changes in the plans after the bond is signed, thereby creating a loophole by which the bonding company may escape responsibility if the contractor defaults.

One word in defense of the lawyers, with whom the author deals somewhat harshly: The onesidedeness, blamed on them, of contracts does not usually arise from their being lawyers, but from a desire to satisfy or protect clients who themselves, be they city, state or federal officials, engineers, contractors or other business men, usually desire to have contracts drawn greatly in their own favor. The client who wants a contract to be fair to both parties will do well to obtain his lawyer's assistance.

MR. SAMUEL E. DUFF:* As a member of the Society I wish to thank Mr. Rollins for discussing publicly and frankly a subject on which most people dislike to go on record. A good, hard kicker is not usually personally popular, but he is very useful.

The kick Mr. Rollins has made tonight is a good one, well directed and with force behind it. It is worth our while to follow up some of the cracks that radiate from the spots on our shell of self-complacency which he has hit.

About 29 years' continuous service in engineering work, half of it on the owner's side and half of it on the contractor's side, have naturally fixed in my mind a number of facts and principles of action in connection with the subject of this paper.

The subject is a large one and the title—"The Relation Between Engineers and Contractors"—properly includes a great deal more than Mr. Rollins has discussed.

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In the paper the word "engineer" is used to indicate the presumably technically experienced advisor, agent or employee of the purchaser of construction work. To make the situation entirely clear it must be remembered that the engineer is only an agent or employee.

The principals to the contract are the owner and the contractor. The signatory parties are the buyer and the seller,—in other words, they are traders.

A man who consumes time and energy in trade without seeking financial gain thereby is either a fool or a philanthropist,—neither of them remain in trade very long.

The principles of trade are simple. The buyer must endeavor to get the most for his money and the seller must endeavor to give the least for the money he receives. When the buyer acknowledges receipt of the goods and pays for them the trade is closed. The governing rule is *"caveat emptor"*—"Let the Buyer Beware."

There are many minor rules governing trade based on morals, law and expediency, but the ruling principles are so stated above and should not be lost sight of when we are discussing contracts.

To say that the ruling principle of trade is immoral or cruel is both incorrect and foolish. The desire for gain is a part of our nature and trading has been indulged in, more or less, by all mankind.

As a faithful agent or employee, the engineer must follow the policy laid down by the buyer, his employer. It is the engineer's duty to interpret the policy of his principal as far as it relates to technical matters as faithfully as he can, with due regard to the principles of common honesty.

In making plans and specifications for some types of construction the engineer can ascertain quite precisely all important factors, but in many types of construction it is impossible to obtain all of the facts without an expense which would be unjustified. When important facts governing a given piece of work are difficult to ascertain, it is undoubtedly best to do the work under some arrangement whereby the contractor cannot suffer actual loss, although at the same time his possible gain is rather definitely fixed. This method is represented by the cost plus percentage, or cost plus fixed sum type of contract. Many owners, however, absolutely refuse to consider a contract of this kind and insist that the engineer should be able to so state the problem that the contractor can make a lump sum tender for the work. Such a situation is practically always found in connection with construction undertaken by municipalities and government departments, where the form of contract is fixed by law.

In connection with work of this character, the engineer is usually required to make an estimate of final cost on which an appropriation or possibly a bond issue is based. It may be evident that many conditions which will largely influence the cost of the work will not be fully disclosed until some of the work has been done.

The above remarks apply to a large extent to practically all types of contract work which have been referred to in Mr. Rollins' paper. Under such circumstances, the engineer is compelled to make his specification broad and, with due regard to the interest of his employer, to so arrange the contract that he has control of the work under all contingencies. It is true that he can interpret the contract and specifications in such a way as to make them very fair to the contractor, or very fair, depending on the knowledge and experience of the engineer and his moral courage and honesty. We cannot expect all engineers to be experienced in every type of work which may be placed in their hands, neither can we expect them always to have great wisdom and high moral courage. We can expect them to be honest and in my opinion dishonest engineers, as well as dishonest contractors, should receive such treatment by the whole fraternity of builders, owners and engineers that their career would be short.

After the engineer has done his best to make his plans and specifications fair with respect to elements on which exact knowledge is lacking, he usually has to submit his papers to the owner and the attorney for the owner. The attorney looks at the matter from the standpoint of a possible law suit, which, of course, is his meat and drink. The owner does not want a lawsuit, but at the same time looks to the engineer and attorney to fully protect his interests.

The result is very often the type of contract and specifications which Mr. Rollins so strongly criticises.

As I have heretofore remarked, the contractor is in trade, or in other words,—he is operating for the purpose of obtaining financial gain. The trade he follows is a hazardous one, particularly so in what is known as general contracting, which is principally referred to in Mr. Rollins' paper. In order to be successful, the contractor must be a man of good judgment, in other words,—his judgment must be right in the majority of cases.

It certainly will be admitted that the making up of a proposal for a general contract is largely a matter of judgment rather than a compilation of figures derived from absolute knowledge. It is seldom possible for anyone to precisely state the condition which will govern throughout the execution of the work. The quantities of materials and labor are always to a certain extent indeterminate and the mechanical means best adapted are seldom clearly defined. The actual net profit which the contractor expects to receive from a particular contract, and which forms a part of his price, must be fixed by his judgment of all the circumstances governing the letting of the contract, the financial responsibility of the owner, the probable trend of the market prices of labor and materials and many other things which may bring about changed conditions, but also another thing which bears on our subject tonight;—he should exercise his judgment on the kind of supervision the work will probably receive, and if possible, by conversation with the owner or the engineer, determine in a general way their ideas as to many details which it is impossible to clearly indicate in the specifications.

Even after a careful investigation of the points outlined and any other important facts in connection with a particular contract, the judgment of the most experienced contractor is liable to lead him entirely astray as far as final results are concerned. His profit may be greatly increased or it may be diminished and turned into a loss. This is a part of the chance inherent to the contractor's trade.

To assume that the owner and engineer should be willing to lower the grade of the work contemplated or pay for the work done a much larger sum of money than is contemplated in the contract because the contractor is losing money on the job, would justify the owner in demanding that the contractor on a highly profitable job should be willing to return to the owner all profits gained beyond a fixed percentage. Such a clause in a contract would not be acceptable to most owners and contractors, who prefer to depend upon their judgment in hope of unusual profit.

Referring to the list of clauses in contracts, which according to Mr. Rollins are always unfair and unjust to contractors, the first one is "Disclaiming responsibility for soundings and other information as to the character of the work." It seems to me perfectly fair for an engineer to allow the contractor to use any information in the possession of the engineer as long as he distinctly tells the contractor that such information is not guaranteed to be correct, but is given to the contractor for what use he may desire to make of it. In the case of borings, for instance, the engineer should tell how they were made and give any other inforamtion which would enable the contractor to judge whether or not they indicate correctly the conditions he desires to know. It is manifestly unwise, if not dishonest, for an engineer to state in his specifications that borings carelessly made should be relied upon by the contractor in making his estimate, but I think it is entirely fair for him to allow the contractor to use the information with the distinct understanding that the contracor must use his own judgment as to conditions not fully disclosed, or make his own investigation before making his bid.

Another point objected to by Mr. Rollins: "The insertion of the clause which may make any contractor's estimates and bids worthless, 'or as otherwise directed.' " In many contracts it is practically impossible to avoid such a clause and usually it is as fair to the contractor as to the owner. In many cases neither the engineer nor the contractor can tell exactly how they will be compelled to proceed at a certain stage of the work in order to produce the desired results. If the engineer set out in his specifications a method which was most certain to produce the results, although unusual and annoying to the contractor, and left no alternative, the contractor would be compelled to bid high accordingly. Should it turn out after the work proceeded that a much less expensive method would produce satisfactory results, the contractor would undoubtedly desire to use it, but without the phrase "or as otherwise directed" the most cordial agreement between engineer and contractor resulting in methods not specified might bring down on the contractor the owner and his attorney when he came to settle up. I think it is perfectly fair to insert this clause in a contract where the engineer describes a method reasonably certain to produce the results. If a more expensive method is necessary, the contractor and the engineer should agree on the added compensation for the contractor and this agreement should be binding on the owner.

The third clause objected to by Mr. Rollins is "Making contractors responsible for work for which the engineers make the plans or require their approval to any made by the contractor and where the engineers reserve the right entirely to control the manner and means of construction." Such clauses are undoubtedly unfair to the contractor and should not be accepted by him under any circumstances, except where the specifications precisely state materials and methods to be used and the contractor has ample means of judging whether or not such materials and methods will produce the result desired. To this case particularly applies the rule requiring "a meeting of the minds of the contracting parties." Should conditions undisclosed when the contract is made require a change from specified methods and materials, a supplementary contract should be made in which the responsibilities of the owner and the contractor are clearly defined.

The fourth objectionable clause presented by Mr. Rollins is "Holding contractors responsible for work which has been built under the direction of the engineer, and passed inspection, unless fraud or gross negligence is proved." As stated this is a rather difficult question to handle. It is often impossible for an engineer to inspect work thoroughly without practically taking entire charge of all the workmen employed by the contractor. In such cases an engineer can only exercise a general inspection of materials and methods. It often happens that bad results appear from which improper materials or workmanship may be reasonably inferred. Either fraud or negligence have occurred, perhaps both. It is usually entirely fair to require the contractor to make good the defective work, leaving final settlement to a time when the matter has been fully investigated. A contractor cannot plead that inspection and supervision by the engineer will relieve the contractor from maintaining such continuous supervision as will insure the fulfilment of his contract.

The fifth clause objected to by Mr. Rollins is "Making the engineer the sole referee in settling all claims." I think a clause of this kind is entirely fair and necessary in most contracts. There are only three parties who can have complete knowledge of the work done under a contract. They are the owner, the contractor and the engineer employee of the owner, who is supervising the work. The owner is not presumed to have knowledge of the details of the construction. The contractor, however, is presumed to have a technically expert knowledge of the work he undertakes. The owner and the contractor are directly interested parties; in other words,—they are the traders referred to above, and they can not, of course, act as referee in settling their own affairs. The only possible referee is the engineer who is supposed to have as much knowledge of the work as the contractor and more knowledge than the owner. It is also reasonably certain that the engineer is honest and that he has backbone enough to tell the owner, his employer, the truth about conditions not covered by the contract, which arise on the work. Surely Mr. Rollins would not suggest that the contractor shall have the power to collect what he pleases for anything the engineer compels him to do, which in the opinion of the contractor is not included in the contract. In discussing this clause Mr. Rollins states that

"The necessity for a decision does not come up until there are matters in dispute, at which time the engineer has already given his decision against the contractor so that he is in a position of a judge who decides his case before he hears the evidence." I am inclined to think that Mr. Rollins has put this rather strongly. The engineer is the only judge of the work recognized in the contract. To say that he will render his decisions without hearing the evidence is hardly stating the reasonable probabilities. I will admit that the engineer may be prejudiced against the interests of the contractor from a desire to obtain favor in the eyes of his employer, the owner, or for some personal reasons which have developed out of the daily contact between the engineer and contractor, but it is not fair to assume that he is usually ruled by such a sentiment. The author, in connection with this clause, suggests the inserting in all contracts of a provision for arbitration of matters in dispute. The customary manner of writing this clause, providing for an arbitrator chosen by the owner, another by the contractor and a third by the two arbitrators already chosen, is in my opinion almost always entirely illegal and not binding on either party. It is probably legal and binding to appoint by name in the contract one or more arbitrators to settle disputes arising between parties to a contract, for in that case each of the contracting parties is presumed to have full knowledge of the experience and qualifications of the persons named to act as arbitrators. To provide that three unnamed persons, however the selection may be provided for, shall be permitted to take away by a decision the rights of either of the parties to a contract is, I believe, entirely illegal when put to the test. It is, of course, entirely legal for the owner and the contractor to agree when a specific dispute arises to submit their case to individuals to be named by the method usually adopted, or otherwise, because they are presumed to be able at that time to select persons competent to arbitrate, and they are also at that time fully aware of just what an adverse decision would amount to. Such procedure, when important matters are in dispute between an owner and a contractor, is not unusual, and if the engineer is broad-minded, will be welcomed by him. To incorporate the general arbitration clause in a contract, in my opinion, is only inviting trouble and expense for both the owner and the contractor.

The sixth clause objected to by Mr. Rollins is "The right to stop work, or any part of it, if for the interest of the engineer so to do, without allowing the contractor any compensation for such action." A clause of this kind is clearly unfair, and no contractor should sign a contract without some provision for compensation due to delays on the work outside of his control. When in charge of work for a contractor or in a position of contractor myself, I have probably created more trouble on account of this point than on any other mentioned by Mr. Rollins. In my opinion the limit of time in which a certain piece of work is to be done should be rather clearly defined in the contract. If the owner delays the contractor in the prosecution of the work in such a way as to add to the cost of it, the contractor should be compensated. On the other hand, if the contractor delays the work in such a way as to injure the owner, the owner should be compensated. If the delay occurs through no fault or negligence of either owner or contractor, any damage arising is a clear loss to both parties and one of the things that cannot be provided for and must be charged to profit and loss.

Mr. Rollins says the *bete noire* of engineers is extra work. I am inclined to say that the black beast who gives most trouble to the engineer is the contractor who bids carelessly and without study of plans and specifications and conditions surrounding the work.

I am equally certain that the careless engineer is the blackest beast the contractor has to deal with.

These evils cannot be entirely taken away from our construction work, but frank and open discussion between engineers and contractors, such as is initiated by Mr. Rollins' paper tonight, is of great benefit. It serves to present to the most interested parties the viewpoint of the other fellow, thus bringing about broader knowledge and showing the financial loss due to careless and inaccurate plans and specifications and to the careless assumption of misunderstood responsibilities by contractors.

I heartily endorse Mr. Rollins' plea that engineers and contractors deal openly and fairly with each other, as man to man, each willing to receive, as well as give, hard knocks, and I add on the part of both, for I am on both sides of the game all the time, *BE CAREFUL.* As the saying is, "If you can't always be careful, try to be as careful as you can."

MR. C. L. MCKENZIE:* Without expecting to add anything of much consequence to Mr. Rollins' interesting and valuable paper, I will just quote one of the clauses from a standard railroad contract and comment briefly:

> "The contractor agrees to indemnify and save harmless the company for and from all claims, demands, payments, suits, actions, recoveries and judgments of every name and description, brought or recovered against it, for, or on account of any injuries or damages received or sustained by any party or parties, by reason of any act of the said contractor, his agents or servants, in the construction of said work, or by, or in consequence of any negligence or carelessness in guarding the same; or on account of the death or injury to the person, or damage to the property of the contractor or any of the agents, servants or employees of the contractor, who shall be engaged in, or about the work to be performed under this contract, *whether such death, injury or damage shall be caused by the negligence of the company, its agents, servants or otherwise;* and so much of the moneys due, or to become due, to said contractor, under this agreement, as shall or may be deemed necessary by the chief engineer, shall, or may be retained by the company, until every and all of such claims, demands, suits, actions, recoveries and judgments shall have been settled and discharged, and evidence to that effect furnished to the satisfaction of said chief engineer."

You will note that the intent is to put this clause in form to make the contractor an insurer of the owner against loss while, and at the place where, the contract work is being carried on, even though the loss is caused by the owner himself, directly or through his agents or employees. The courts (original, appeal and supreme) are not yet through with it, but there is a fair chance that this clause will yet cost contractors a lot of money.

Now it seems to me not the reasonable and logical way, even if it is possible, for the owner to relieve himself in this manner of his natural responsibilities, such as arise from causes, or from the acts of persons, that he is ordinarily responsible for, legally or morally, or both, and that the contractor temporarily serving him cannot regulate or control. No contracting firm is in the insurance business, nor qualified to estimate the proper premium to charge for such insurance. Moreover, the owner who insists on such a clause is to an extent employing compulsion, since a contractor who includes enough in his bid price to properly cover such risks will very seldom, if ever, secure the contract under existing conditions of competition. My own opinion is that the reasonable and logical plan is for the owner (who receives the ultimate benefit of the work) to carry the risk of loss from natural forces which neither party to the contract can control; but this can, perhaps, properly and logically be made a special matter of agreement.

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The contractor, of course, *can* reasonably assume, and should assume full responsibility for the act or neglect of his own agents and employees while on the work and for the safety and adequacy of his own equipment, methods and appliances. But, if he is to accept such wide-reaching clauses as first quoted, the contractor should receive better prices than are at all likely in open competitive bidding. Unfortunately, there seem still to be many contractors who will sign any form of contract without question, trusting to "luck," or hoping in case of trouble to find some legal loophole to relieve them from enforcement of the stringent requirements of the agreement as literally interpreted. Such clauses in railroad contracts and others referred to by Mr. Rollins could usually be modified and adapted to the fair requirements of any given case, except for the restriction of the engineer's authority. It is surely an ungrateful task to argue with the engineer for modifications in a standard printed form of contract, drawn originally years before, and re-worked and revised by lawyers intent in the interest of their client on improving the provisions as nearly as practicable to the point where all the burdens in matters of general responsibility are placed on the contractor, and all decisions and control are in the hands of the owner, whose final authority in such general matters is lodged not with the engineer in charge (who has exact knowledge of the actual conditions and needs), but in some inaccessible high official, guided by *general* advice and *general* counsel, and without time or opportunity to learn the specific facts and specific needs of the case. Why should not the owner's engineer be given authority to modify these general clauses of the contract—of course, under advice of some *accessible* legal counsel—to make them fit the reasonable requirements of the particular case, somewhat in the same way that he can modify plans and specifications?

The engineer entrusted with handling large construction should know considerable law himself and, incidentally, should appreciate that a fair agreement, fairly balancing the responsibilities between the two parties, is safer, less likely to cause trouble and suits, and more likely to be enforceable than a one-sided agreement that puts all, or nearly all, the burdens and responsibilities on one party.

It is to be assumed that, to serve his own best interest, the owner will aim to employ an engineer of ability and experience in proportion to the importance of his position and responsibility. Such an engineer will be correspondingly broad in his views and undoubtedly have a clearer, more definite conception of the effect of the contract provision as actually to be applied to a given piece of work, than a lawyer not in position to know the detailed facts.

MR. THOMAS P. ROBERTS:* Mr. Rollins presents cases from his own and from the experience of other contractors amply justifying him in his views that contracts should be more liberally and intelligently construed than is generally the case where disputes with the engineers arise.

He presents the subject in a fair light from the point of view of the contractor and should be, and doubtless will be, met in the same spirit by the engineers and the capitalists who are behind them. "It is the letter which killeth," for very often good contractors in public works, honest and diligent in their work, have been financially ruined by constructions of inequitable specifications in contracts.

Let us for a moment look into the *raison d' etre* of contracts. First, we have the enterprising capitalist, or company, and promoters willing to invest in some enterprise. Capital is proverbially timid and must be assured of a return, etc. Next the company employs an engineer to get up plans and estimates of cost of executing the contemplated work. His plans being approved, the engineer is then authorized to let the work according to carefully scrutinized specifications.

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*Civil Engineer, U. S. Engineer Office, Pittsburgh.

The interests of the company in the case fundamentally are concerned alone with questions of time and good, honest workmanship by the contracting party. Fearful, however, that the average bidders on work are schemers and inately dishonest, the specifications are made as tight as the ablest lawyers can make them.

This fear, the writer believes, results very often in adding to the cost of the work, and here reference is not made alone to extra work costs, but also to prices for all the items of work simply because it is impressed upon the bidders in numerous ways that practically all risks, losses through delays, etc., must be assumed by himself or themselves. Risks are vague and indefinite, but still a figure of dollars must be set upon them, and these the bidder distributes over the known items as best he can. This is part of the bidder's work which he does in fear and trepidation. He thinks if his figures are too high he will not get the job, and if too low he may lose money. It is sheer guesswork and nothing else with him.

It is well enough for the contractor to be very specific as to materials furnished and as to the nature of workmanship desired, so that no frauds may be perpetrated, but looking after such matters are the simplest duties of the engineer. When, however, it comes to the matter of unexpected risks to be encountered, it is "let George do it" for the contractor—for so it has been instilled into the specifications by "well-trained legal minds." The legal minds, properly enough, think the experienced contractor should know more about risks than they do, and the capitalist, of course, agrees with that idea.

What, however, is the not infrequent result? Contractors, no matter how diligent, honest or faithful, have their cofferdams carried away by floods time after time; the elements some years apparently combining against them, until finally their resources are exhausted and they are declared to be bankrupt. Meantime, however, the company has paid him high "risk" prices for the parts of the work that the bankrupt actually completed. After much delay in courts and otherwise the job is again let and generally at extravagantly high prices to another contractor, for there has been a demonstration in value of the work done. Now it is clear, that had the first contractor been aided by the company in his time of pressing need, the final total cost of the work would have been less to the company.

It should be the case as far as possible in all contracts that for plain sailing items, such as for materials and workmanship on them, bids should be based upon market prices, plus the profit the bidder thinks should be his; but for risky parts of the works, such as result from failures of dams, extraordinary pumping, earth or rock slides, bursting of mains, difficult underpinning work, delays due to strikes or transportation troubles, fires, etc., the facts in the utmost detail should be made known to the engineer and carefully and independently checked by him, so that he may calculate the labor and other costs to make them good, allowing an agreed upon but reasonable profit to the contractor for the use of his men, appliances, etc.

In this way, and in this way only—when the matter of risks is removed from the shoulders of the contractor—will the cost of work be reduced to a reasonable minimum. It may be objected that this would be practically putting contracts on the basis of the day labor system. What of it? It is often done to great advantage and the practice might well be extended. True it adds much to the duties of the engineer, but he will assume such duties gladly, for his own reputation is more or less involved in the trouble.

Of course, in such a system the engineer would be called upon to prescribe just when, and to what extent, force accounts should be applied and, in case of disagreement with the contractor on these points, then a disinterested experienced engineer arbitrator should be called in by joint agreement.

In no case should the company be called upon to assume responsibility where contractor proceeds with methods of doing extra work disapproved by the engineer and contrawise; the contractor should not be called upon to shoulder risks where the methods are prescribed by the engineer and followed by the contractor.

In the case of many contracts as at present drawn, the engineer is the designated umpire whose decisions are final, nevertheless, sad to say, it may not go well with the "umpire" if he manifests any sympathy with the woes of the contractor. The capitalists are surely blind to their own interests when they attempt to bind not only the contractor's but their own engineers in steel-ribbed jackets.

The relations between engineers and contractors are becoming more and more strained and difficult of adjustment with the ever-growing diversity of engineering operations. These operations all the time, however, may be divided into two groups. First, physics embracing things mechanical, electrical, pneumatic, hydraulic, etc., wherein it is generally recognized that the dictum of the engineer is supreme; second, the grand division of work has to do with the problems of transportation delays due to disasters, etc., and herein enters the "personal equation," or, let us say, human limitations to be taken into account.

The law settles disputes as to rights according to statute, and is building itself up only gradually through the court, for the lawyers on both sides invariably find decisions which they think sustain their points of view. Seldom do the courts' opinions wander far from the particulars at issue, hence hoped-for broad principles are not often laid down.

Why not, therefore, settle cases as far as possible in a friendly court of arbitration? Contract cases at bottom relate, almost invariably, to facts, and the "viewers" who know most about the pertinent facts should be the best judges as to their relative importance. If, however, it is to be a "beat" by one side or the other, then, of course, the courts are the only places to go. Even in the courts, however, the capitalist is apt to suffer the most, because juries often, and often unjustly, regard them as beings without souls.

Put to the rack, the capitalist is justified in maintaining his side to the utmost, for, after all, he is not responsible for planting the seeds in his contracts which bore fruit the very opposite of what he expected when he bought them from the seedman. The restrictions he sanctioned were with the best intention to be guides for the contractor and inserted for the express purpose of avoiding disputes.

Who, then, are the parties responsible for the estrangements between the engineers and the contractors? Let us name them. They are the capitalists, the lawyers, the engineers and the contractors; all of them, willy nilly, having failed to enter their protests at the proper time, and to urge due consideration of the human factor in the making of contracts, they permitted the bad elements of suspicion and mistrust to prevail, and after that trench warfare ensues, when heads are shot off on sight.

Mr. Rollins suggests that the severe terms of contracts are aimed, not at the honest, but at the "scalawag" or inefficient contractors; but has not the company the right to award its contracts to persons of its own selection from the list of bidders? If they select inefficient parties it is their own fault.

Mr. J. W. Rollins:* The writer has read the discussions with much interest, and notes with great satisfaction that most of the writers agree with him in most points at issue; but there is some opposition to the abandonment of the obnoxious blanket clauses.

The writer must again affirm that these clauses do not protect the engineers from poor contractors; but many times work an injustice, which even the engineers cannot help, to honest contractors, where the issue comes to a lawsuit; and that the protection against poor contractors is given engineers in their requests for bids, which explicitly gives them the right to throw out all bidders who cannot qualify as to financial standing, equipment and experience.

An opinion is expressed that the paper as read is "hard on the lawyers." A lawyer is a professional man who tries to interpret law, and a strict legal interpretation of a contract must mean just what is written in the contract, unless so much is written in that one part conflicts with the other, or is so much at variance with public opinion and public policy as to nullify its provisions. The lawyers are in a different position from the engineer, who properly is an *arbitrator,*—the engineer can settle disputes on the basis of justice to both parties; while a lawyer, acting as such, must advise settlements on a strictly legal basis, which may be far away from a just one. The writer has no reason to doubt that the lawyers are just as faithful to their profession and to their clients as the engineers.

The writer in closing wishes to express his appreciation of the courtesies extended to him on his visit to Pittsburgh by the Secretary and members of the Western Society of Engineers.

*Author's closure.

UNIVERSAL ELECTRICITY SUPPLY

By Samuel Insull*

Perhaps it would be more fitting if I should address myself to the subject that has been assigned to me at one of your regular technical meetings rather than at an annual festive occasion like this. The topic on which I am to speak, namely, the question of universal electricity supply, relates to the difficulties or problems with which you as manufacturers have to deal every day in the week. It is the question of keeping the dollar invested—invested in one branch of the manufacturing business—steadily employed all the time. It is the question of how to produce and to distribute and sell energy at the lowest possible cost to the producer and at the lowest possible cost to the user. Therefore, it is a dry subject, and one, as I have said, hardly suited to a festive occasion.

Moreover, I feel some hesitation—hesitation that I always give expression to if I am appearing before an engineering body—from another cause. I have not had the advantage of an engineer's training. My engineering education has been gained in the College of Experience, and not, unfortunately for me, as I have felt on many occasions, in one of the great technical institutions which, as a whole, have done so much to further the technical training of men, leading to the technical experience of such a body as is represented here this evening.

THE WORK OF WESTINGHOUSE AND DE FERRANTI

In the early days of the production and distribution of electrical energy we were obliged necessarily to confine our undertakings to relatively small areas. The form of electrical energy which we produced—was of such a character that, owing to the limitations of the translating devices then available, it did not lend

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This is a revised stenographic report of an address delivered at the annual banquet of the Engineers' Society of Western Pennsylvania, in Soldiers' Memorial Hall, Pittsburgh, Pa., on Monday evening, February 14, 1916.

*President, Commonwealth Edison Company, Chicago.

itself to the high pressures which are absolutely necessary for economical distribution over large areas.

We owe to a townsman of yours (a townsman by adoption), not so much as an inventor but as an enterpriser, the early introduction into this country of the alternating-current system of electrical production and distribution. I refer to my lamented friend, Mr. George Westinghouse, who was far-sighted enough to see that, with the development of the manufacturing business of the country, it would be necessary to produce electrical energy in such form as would allow of its being transmitted at relatively low cost over great distances.

About the time that Mr. Westinghouse introduced the inventions relating to alternating-current production and distribution, a young Englishman by the name of de Ferranti conceived the idea of massing electrical production. He established his generating station at a point on the River Thames below the fixed bridges of London, where he could, without second handling, obtain coal from the mines in the North of England. The fuel was shipped to London in steamships that could go right up to the dock of his generating station. The first long-distance transmission line (that is, long for those days), probably eight or ten miles long, conveyed energy from the Deptford station, erected by Mr. de Ferranti, to the West End of London. That was the first effective effort to attain long-distance transmission. We would think that distance today of very little significance; a point eight or ten miles distant is now practically next door to the generating station.

ELECTRICAL DISTRIBUTION OVER LARGE AREAS

At the time that Mr. de Ferranti first projected his scheme (1889) eight or ten miles was considered a tremendous distance to transmit energy in the form of electricity. The engineer of the Deptford station and transmission was probably ten or fifteen years ahead of his time, or rather ahead of the time when it became possible to bring such a scheme to a financial success. Over twenty years after, when Mr. de Ferranti was president of the (British) Institution of Electrical Engineers, he sketched out in his presidential address a scheme of electrical generation and distribution to cover the greater part of England, certainly that portion of England in which manufacturing is most dense. The plan outlined provided for the generation of energy at the mouth of the coal mines and its transmission practically over the whole area extending from the east coast of England to the coast of Wales.

In this country probably one of the greatest exponents of the same idea is Professor C. P. Steinmetz, the head of the Research Laboratory of the General Electrical Company at Schenectady. In some of his public addresses, Professor Steinmetz has referred to the possibilities of electrical distribution over large areas, comparing the great transmission lines that must exist in the densely settled portion of the country to the great trunk lines of the railroads. He has described the possibilities of those great transmission lines, supplying them from generating stations, whether those stations have as their prime movers steam engines or steam turbines, or whether they may possibly have the advantage of hydro-electric plants where water-powers can be developed with economy.

REMARKABLE IMPROVEMENT IN PRIME-MOVER EFFICIENCY

The great progress that has been made in the efficiency of prime movers from the time of the introduction of the steam turbine, relatively but a few years ago, is a very important factor in connection with this development. Energy can now be produced from prime movers having a capacity as great as from 40 000 to 50 000 horse-power. It is quite within the range of possibility that within a few years we shall be using very much larger sizes. Indeed, I fully expect within my own day to see prime movers having a capacity of from 75 000 to 100 000 horse-power produced from electric generators on one shaft.

The essentials necessary for distribution over wide areas are prime movers of very high efficiency, such as I have spoken of, alternating-current transformers of high efficiency, and transmission lines of very high capacity. The improvement in the efficiency of prime movers in the last few years has been upwards of 35 percent; and I am strongly of the opinion that in the next few years, probably by the adoption of very much higher steam pressures, we shall obtain still greater improvement.

It is not at all beyond the range of possibility that eventually, and indeed, in our own day, we shall be operating steam turbines with the aid of boilers running as high as 1000 pounds steam pressure. There should not be any great obstacle to the achievement of the efficiency that would come as a result. It would seem to me that this is a good deal nearer today, relatively speaking, than the steam turbine was not so many years ago, when we depended on cruder forms and less efficient forms of prime movers.

ELECTRIC SERVICE IN LONDON AND CHICAGO COMPARED

To give you some idea of what can be done by massing production and distribution, I will quote from some figures that I am fond of using, making a comparison between the output of electrical energy in the city of Chicago with 2 500 000 people and in the County of London with about 7 750 000 people.

The electricity-supply business in the County of London, owing to the condition of the laws there, is operated in a manner exactly opposite to that which is practiced in most of the large industrial centers in this country. I think that there are 63 or 64 different electricity-supply undertakings within the area of the County of London, while within the city of Chicago there is one undertaking. The maximum demand in Chicago on the central-station system of the city is 338 000 kilowatts. The maximum demand in the County of London is 225 000 kilowatts. The kilowatt-hours generated in the city of Chicago in 1915 were 1 200 000 000. The kilowatt-hours generated in the County of London in the same year were estimated at 571 000 000.

As I have stated, the population of Chicago is about two millions and a half, and that of London is well toward eight millions. We generate in Chicago 500 kilowatt-hours per capita per annum, and in London they generate 74 kiolwatt-hours per capita per annum. The cause of this great difference is, of course, the selling price. We manage to distribute and sell the energy that we produce in Chicago for just about the average cost of the energy generated in London; that is, the price that we obtain, which is comparable with the cost in London, has to give us a return on our investment, taking care of the necessary interest and depreciation, while in London they have to earn the sum necessary for profit, interest, and depreciation above our selling price.

UTILIZING THE DIVERSITY OF DEMAND

Within the last few years we have had an investigation in the city of Chicago which has led to a report being made by a commission of "Investigation on Smoke Abatement and Electrification of Railway Terminals." This report sets forth among other things some data upon the question of the electrification of steam railroads within what the commission called the "Chicago area." I do not propose to refer to the figures of that report with any idea of advocating the electrification of steam railroads. That is a question that the steam railroads themselves have to settle in their own way and at their own time. But the information contained in that report has quite an important bearing on the question of the centralization of the production of energy and the economics of the production of energy.

As I have told you, the maximum demand on our central stations in Chicago is 338 000 kilowatts. If the steam railroads within the "Chicago area" were electrified, their maximum demand for power would be 125 000 kilowatts. All the energy now produced by owners of individual power plants in this area amounts to about 264 000 kilowatts. If this amount is added to the two preceding figures to get the total power requirements in the area with the steam railroads electrified, the total amount would be 727 000 kilowatts.

The energy demands of these different classes of requirements are so diversified that if you analyze these figures still further you will find that the coincident demand for all these various purposes is only 577 000 kilowatts. Thus, there is a difference between the maximum demand of these requirements, considered separately, and the maximum coincident demand of all of them considered together with their energies supplied from one source. This difference in demand would be 150 000 kilowatts.

TREMENDOUS SAVING IN FUEL POSSIBLE

What does this saving of energy by utilizing diversity of demand mean in relation to the saving of fuel? If all the energy required in the "Chicago area" for the purposes stated was produced from one source, the fuel saving alone would amount to 6 000 000 tons of coal a year, to say nothing of the savings that would be brought about by lower operating expenses and lower investment by taking advantage of the great difference between the collective demand of the industries considered separately and their coincident demand.

I have carried these figures further, applying the principle to the whole country. I do not mean for one moment to suggest that it is possible to have one great system for the production of electrical energy and its distribution applicable to the whole country. But taking the figures given in the United States Census Reports and using those figures in connection with the figures of the Smoke Abatement Commission of Chicago, one is enabled to arrive at some idea of the savings that can be effected if the energy requirements of the country are massed in the districts in which there is great density of population, great density of manufacturing and great density of transportation.

I will not burden you with the details of the figures; but if the energy required for ordinary present central-station purposes, electric railways, steam railways (if electrified), manufacturers, mines and quarries, ice making, town water pumping, drainage, farm power and electric vehicles—if, say, this production and distribution could be massed in the densely populated districts of Pennsylvania, or in the densely populated districts of Illinois, or in the densely populated districts of New York state, or in any of the densely populated states of the Atlantic seaboard —the diversity between the aggregate individual demand and the coincident demand would be so great that it seems almost hopeless to attempt to calculate it.

GREAT OPPORTUNITIES NOW GOING TO WASTE

Take together all those industries I have named, looking forward relatively a few years to, say 1925, these businesses will require in the individual aggregate about 68 000 000 horse-power. Massing them in each separate territory, as far as it is possible to mass them and come within areas of economic distribution, and the saving would be upwards of 20 000 000 horse-power. And if you represent that saving in the saving of fuel alone, this saving, based upon an estimated fair average price for coal the country over of $2.50 a ton in 1925, would amount annually to $823 000 000.

Let us transfer our attention from the nation to local communities. I have in mind a community not so very far from Pittsburgh, where the business of electrical generation and distribution in the densely settled portion is conducted by one interest, while in the area outside of the municipal limits this business is conducted by another interest.

Outside of the city the maximum demand for energy comes in the morning; inside of the city the maximum demand for energy comes in the afternoon. The institutions that operate the electricity-supply business outside of the city have idle plant during the hours of the day when the institutions producing energy inside of the city have their maximum demand, and the city institution has an idle plant when the institutions producing the energy outside of the city have the greatest demand on them for power. Or, to use a hydro-electric expression, the city lets the water run over the dam in the morning and the country lets the water run over the dam in the afternoon.

That sort of thing is going on all over the country. It is an economical absurdity. It is a waste of capital. It is a tying-up of money that is entirely unnecessary. It leads to greater operating cost, and consequently, to greater selling price to the user.

WHAT CHEAP ENERGY MEANS

If you will take the duplication of investment and the excessive operating expenses which come from the situation which I have just described, and add the two together, the total investment loss in and around the community to which I refer, and which has a population not any larger than that of Pittsburgh and the surrounding territory, is $6 000 000.

This is a subject in which all you people as manufacturers, and, indeed, all the manufacturers of this country, are vitally interested. In discussing it I am open to the charge that I am acting as my own salesman; but I am pleading for the cause in which my business life is spent. After all, what we are all after is to get the greatest possible use out of a given amount of capital. If we, by pursuing one business policy or another, can increase or decrease the cost of production of all manufacturing businesses where the cost of energy is an important element of total cost, we are certainly discussing a subject not merely of local interest and not merely of interest to one individual in particular, but a subject which is of great interest to all of us, whatever may be the line of business that we are following.

Cheap energy means lower cost to the manufacturer; it means lower cost to the transportation company, and that is again reflected in lower cost of rates of transportation or else in increased profits to the transportation companies.

THE BENEFIT TO SOCIETY

The possibility of obtaining cheap energy not only in centers of population but in country districts has a great bearing upon the social life of our people. The possibility of the workman being able to obtain employment away from centers of population, owing to the production of cheap energy in country districts, has an important bearing upon the physique of the younger generation. I know of no subject, except possibly the subject of transportation, that has so much to do with the well-being of the people as a whole as the production and distribution of cheap energy to all classes of our population, and to all communities, whether they be large or small. Cheap energy can be achieved by the massing of production and by the massing of distribution by means of high-tension transmission lines. This massing of production and distribution should enable us to carry energy into all parts of the country at such a price as would enable the manufacturers, alike in the country community and in the great centers of population, to compete on an equal basis.

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AFTER THE WAR

By Alba B. Johnson*

It was with great pleasure that I accepted the invitation extended to me by your Secretary to be your guest this evening, because Pittsburgh is the place of my birth and the scene of my earliest recollections. At a very early age I sprang from Pittsburgh and landed at Philadelphia during the dark days of the Rebellion when Lee's Army was threatening Pennsylvania and the campaign was beginning which culminated at Gettysburg.

We are now in the midst of a great world-war in which, in God's mercy, we have not as a nation become involved, but which nevertheless, vitally affects us. It profoundly enlists our sympathies for the sorrows and sufferings and death of those who are engaged in it. Our sympathies and our generosity are deeply aroused by the necessary and the unnecessary sufferings of those who are enmeshed in the war without being a part of it. For reasons of humanity we eagerly hope for an early end to the war, irrespective of whether our commercial interests are affected favorably or unfavorably, but we can clearly see that when it comes it will bring with it vast changes in world conditions, and that years will be required for this readjustment.

Before the war began, we as a nation had cut loose from the economic policies which in the main had been followed for half a century, and under which we had grown strong and rich. The tariff under which our industrial system has been built up, had been removed, and a new principle was adopted, namely, the taxation of wealth instead of consumption. Under the operation of this new tariff our exports rapidly declined, our imports largely increased, and a deficit of national revenue resulted. The business of the country suffered widespread depression. It was doubtful whether certain industries could survive under the new condi-

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tions which were imposed. Then like a thunderbolt from a clear sky, the war began. The finances of the world were paralyzed, moratoria were declared in many countries, armies were mobilized, ships were taken, and for a few months international commerce ceased. Because it ceased we no longer felt the stress of foreign competition, and the evil effects of an unwise tariff law were neutralized.

It should have been evident that soon our foodstuffs and manufactures would be needed by the nations at war, but it was nearly a year before this foreign demand was sufficient to infuse prosperity into our languishing commerce. During the second and third half-years of the war, vast purchases have been made and vast contracts have been placed which have demanded for their payment sums much larger than Europe could spare from her current resources to meet, and she has therefore borrowed from us an amount unprecedented in American finance, to equalize her obligations to us. Hitherto our foreign loans have been few and small. These great loans mark the entrance of our country into the world's finance as an important power, and it becomes vitally important for us to forecast the conditions which will follow the war in order that we may be prepared to adjust ourselves to them. To do this we must consider our needs at home, the changes which will be caused by the war and the preparations which we must make against those changes.

The principal factors at home are our finance, the situation of our railroads, the tariff, labor and our merchant marine.

The Federal Reserve Act has dealt wisely with our financial system, and has provided a flexibility to our currency from the lack of which we have suffered for fifty years. There is unlikely to be any shortage of money following the war, because of the accumulation of profits, and because the discontinuance of war contracts will release the funds which they have employed as working capital. These funds must immediately be employed in other contracts, or they must pile up in the banks. Therefore, no financial crisis is likely to follow the closing of the war, and were there any disposition for one to occur, our existing provisions are ample to deal with it.

The railroad situation is better than it has been because, after putting into effect every conceivable economy, the railroads are now afforded the increased traffic due to our two phenomenal crops and the stimulus to manufacturing resulting from war orders. The expenditures incidental to the execution of these percolate through every line of business, and for the time create a universal prosperity in which the railroads share. The lessons of last year are not yet forgotten, however. The railroads are subject to regulation of rates downward, but to no protection against increase of wages and other expenses upward. They are subject to regulation by the Interstate Commerce Commission, and by the regulating commissions of the various states through which they run. They are targets for increased taxation and increased legislative exactions. It has not been shown that, under average conditions of good times and bad, their earnings are sufficient to provide reasonable dividends whilst also providing adequately for maintenance and depreciation. During 1915 new railroad construction ceased. The railroads ought to be ensured such a return upon their capital as to make their securities securely profitable, and to attract the new capital necessary for the continued growth of railroad facilities to keep pace with the growth and development of the country.

In the past we have never had a scientific tariff, by which I mean one carefully framed to protect American industry, whilst at the same time securing for our commerce the maximum benefits to be derived from allowing other nations access to our markets for such of their products as we can admit most advantageously to our own interests. Our custom has been for either party upon accession to power to enact by vast negotiations and logrolling, a tariff generally conforming to its views, but rigid and inflexible, and to adhere thereto as long as possible. It gives no provision for defense against changes of tariffs or of customs regulations by other countries, and confers no powers of negotiation upon our Government. If we are to derive the greatest possible benefit from possessing the largest and best market in the world, we must enact a bargaining tariff, and to this end I favor a permanent tariff commission to study tariff questions at home and abroad, and to administer the tariff laws under such general laws as Congress may enact. We should provide ample protection to those industries which have grown out of the withdrawal of imports, due to the war, and place them in a position of reasonable security when peace is restored.

Probably the most important question which has been forced upon our nation by the war is the absence of a merchant marine. The vast depletion of tonnage due to the war must be rebuilt before ocean transportation can be again sufficient for the world's commerce. The American people are earnestly desirous that their fair share of this tonnage shall be built in American shipyards and operated under the American flag. They are also unwilling to permit American seamen being placed upon the lower level of pay and the lower standard of living of other nations. The question resolves itself into a simple one. As the cost of operation of foreign shipping is well known we have no alternative, if we wish to see the American flag restored to its rightful place upon the ocean for the transportation of American merchandise and to furnish the auxiliaries required for our army and navy in the event of war, but to grant national aid at least equivalent to the difference of standards of living and of compensation which we wish to apply to American seamen. Nothing more than this is necessary. Nothing less than this will accomplish the purpose which we have in view.

When the war began and for some months thereafter, the depression of business was such that our supply of labor was much larger than could be furnished with employment by our idle industries. The withdrawal of alien reservists to join the armies of their respective nations was scarcely sufficient to reduce the acuteness of the prevailing unemployment, but the stimulation of our industries by war orders has given work to all who seek it, and we are now suffering from a shortage of labor. This condition will probably become more intense as long as the war continues. Competition of employers for their necessary workmen has resulted in raising wages in many lines to rates higher than organized labor could generally demand. These higher rates have reacted upon the entire labor situation and will doubtless so continue until the war is over when a readjustment will follow. This readjustment will of course be resisted, but will have to be governed by the immutable law of supply and demand. The labor necessary for reconstruction of the devastation of Europe will be required there, and even if immigration should be checked by law, the requirements of Europe will be an important factor in the labor situation in America. The termination of war contracts must cause a dislocation of business in America, and the history of every previous disturbance of business must result. Sooner or later according to the seriousness of the disturbance, trade will be restored to its accustomed volume, reemployment will come. Enforced economies will result in accumulated savings, creating new resources for investment and prosperity will eventually be reestablished.

Turning now to conditions abroad, we shall find that America will occupy a preeminent position in the world's finances. European capital will be needed for the work of reconstruction in Europe, and, from her accumulated resources, America will be in a position to finance countries which have hitherto been borrowers from Europe. This will create new openings for our foreign trade.

Many goods which have been produced in Europe by hand must, because of their reduced labor supply, be made by machinery. France already has a commission in the United States investigating this subject. It will follow that the preeminence of Europe in the highest grades of goods largely produced by hand labor, will no longer exist, and that we shall be more nearly upon a parity with Europe in supplying machine-made products to other countries. The position of the United States in foreign trade should therefore be improved.

The drawing together of the British dependencies and the mother country by the war, and the necessity for conserving British trade, are likely to bring about closer bonds of commercial union between them. A conference of British chambers of commerce to consider this important question has been called to meet in London next month. Furthermore, as England has had to bear a large part of the financial burdens of her allies, it is likely that some closer commercial alliance amongst them will be formed at the close of the war. Whilst not particularly directed against the

United States, such measures cannot prove helpful to our commerce.

International trade must be reciprocal or it cannot long continue. If we sell to other nations we must also buy from them or the international balance of trade will be disturbed. For the first time in our history we find ourselves largely a creditor nation with surplus resources for investment in foreign lands. To obtain the full advantage of our position our bankers should take great care that our funds shall be loaned upon conditions that will ensure a foreign market for our goods. It must not be forgotten that the present balance of trade in our favor is abnormal and temporary. This balance exceeds $1 500 000 000 per annum, but it is largely made up of commodities for which in times of peace there is little demand. Our plans for the future must be based upon creating a demand for our normal exports.

In order to compete with Germany, we must imitate the continuous, laborious, persistent work by which her enormous foreign trade was built up. We must imitate the German methods of thorough education of young men for our foreign trade. We must fortify ourselves by strengthening our representation wherever possible and by creating such financial relations as will tend to remove the business from competition. Our sons and employes who go abroad as our representatives must be willing to remain not one, two or three years, but must identify themselves with the countries to which they go. We cannot successfully compete with British goods until we place ourselves in a position such as England holds, by investing in, developing and managing business enterprises in foreign lands.

In summing up I would say that we must learn to correlate the efforts of manufacturer, merchant, banker and investor. I have been much impressed by the timidity of our bankers in venturing any investment in foreign finance, and especially in enterprises requiring patient development. Our manufacturers have had to fight single-handed for so much foreign trade as they have secured, but it is wonderful how well some have succeeded when one realizes the difficult competition they have had to meet. To many others, foreign business is an unknown, dark and dangerous field, which they enter only with great reluctance. The National

Foreign Trade Conventions are doing much in the way of educating the smaller manufacturers.

Amongst the preparations necessary for the extension of our business after the war, is the removal by proper legislation, of every doubt which may exist that Americans are free to enter into any combination or co-operation for the extension of our trade that is permitted to their competitors of other nations. The restrictions of the Sherman Act cannot be extended beyond the borders of the United States without disastrously affecting our foreign trade.

I rejoice at the establishment of American banks in South America and other foreign countries, and in the creation of such organizations as the American International Corporation and the Latin-American Public Works Corporation, I see the first great systematic attempts at the correlation of effort to which I refer. I hope to see many similar enterprises formed representing different lines of business, for by such efforts only can we effectively meet the world's competition and place our nation in the foremost position as a factor in the world's commerce.

THE NECESSITY FOR A NATIONAL DEPARTMENT OF PUBLIC WORKS

By Isham Randolph*

I value the privilege of addressing you upon a subject which I deem of National importance. That subject is nothing less than a National Department of Public Works.

I stand before you, a veteran in the ranks of Civil Engineering, making no claim to consideration as an accomplished engineer, but I am an engineer who has accomplished some work that will endure. I started on the hard road which I have traveled, long before numbers of you had tasted the breath of heaven or felt the life blood pulsing through your veins, and during thirty years of my life's work I have been in frequent contact with the agencies of the Federal Government which conduct the public works of the land. The result of this contact has developed in me the firm conviction that a need exists for a National Department of Pubilc Works. This conviction grew and strengthened in me until at last I evolved a bill containing what I believe to be the vital principles which should exist in such a department. This bill I first made public in April, 1913, when I brought it before the National Drainage Congress convened in St. Louis. It was discussed by a committee of that Congress and some wise suggestions were drafted into it. I will now read it to you, not as the last word in such needed legislation, but as a draft to be studied and improved upon by such addition or subtraction as maturer judgments and more constructive statesmanship shall dictate.

A BILL TO CREATE AND MAKE EFFECTIVE A NATIONAL DEPARTMENT OF PUBLIC WORKS

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled.

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*Consulting Engineer, Continental Bank Building, Chicago.

That the creation of a Department to be designated and known as the Department of Public Works of the United States is hereby authorized. The head of this Department shall be designated as the Secretary of the Department of Public Works and he shall be appointed by the President of the United States with the consent of Senate thereof and he shall be a member of the President's Cabinet.

The first duty of the Secretary of the Department of Public Works shall be to perfect a working organization for the purpose of carrying on all of the public works of the United States other than those which pertain to National Defense or work wholly relating to navigation and light house construction and service.

He shall appoint a Commissioner of Public Works who shall be a man of recognized ability and successful accomplishment along lines of engineering science and construction.

This election and appointment shall be made with the full knowledge and approval of the President of the United States and the man so appointed shall hold office until disqualified by physical or mental infirmity, old age, moral delinquency or demonstrated unfitness. In consultation with the Secretary, the Commissioner of Public Works shall organize office and field forces sufficient in number and suitably qualified to carry out the intents and purposes of this act which are as follows:

To carry to completion all constructive works, such as public buildings, levees, dams, roads, bridges, structures and improvement works of every description and kind authorized and provided for by Congress and placed under the jurisdiction of the Department of Public Works.

To secure physical data pertaining to rivers, swamps, arid regions, to procure existing maps showing the natural and political divisions of the United States and its territorial and insular possessions.

To secure copies of all topographical maps of accepted reliability and to make topographical surveys of all areas under the control of the United States within which accurate knowledge of the earth's surface seems either necessary or desirable.

To study the meteorological data which has been accumulated by Governmental or other agencies with a view to determining flood expectancy.

To study the characteristics and capacities of the streams of the country for the purpose of determining what had best be done, and how, to avert flood disaster.

To select suitable reservoir sites for storing flood water with the purpose of lowering the flood planes of streams and later, releasing the waters so stored for the purpose of aiding navigation during dry periods and emptying the reservoirs in advance of recurring excessive precipitation.

To study those drainage problems which by reason of civil divisions are interstate in their scope, and to devise plans for draining swamps and overflowed lands in cooperation with States, Counties, Townships, or Municipalities upon an equitable basis of division of cost.

To select available sites for the development of water power.

To gather and preserve data relating to arid lands and the sources from which water may be secured with which to irrigate these lands.

To prepare plans for such structures as it may be necessary or desirable to build in carrying out the purposes of this bill as hereinbefore set forth, together with estimates of cost and recommendations relating thereto.

Those works to be first considered and reported upon, the importance or necessity of which has been demonstrated by disasters creating National sorrow and sympathy, for the purpose of reclaiming lands laid waste by such disasters and restoring them to the Nation's sources of wealth production and permanently thereafter preventing a recurrence of like disaster.

The Secretary of the Department, with the approval of the President, shall present to Congress at each session such projects as he deems meritorious and for which there seems to be an urgent need, together with estimates of cost and his recommendations thereon.

The Secretary shall present each year a report of the operations and expenditures made in accordance with the intent and purposes of this bill and he shall prepare and present a budget setting forth the financial needs of his department, both for administration and constructive work for the fiscal year next ensuing.

The salary of the Secretary of the Department of Public Works shall be the same as that of the Secretary of War and the salaries of the employees of the Department shall be determined by the Secretary with the advice of the Commissioner of Public Works and the approval of the President.

All coastal harbors shall remain as now in charge of the War Department. All navigable rivers above their harbor entrances shall be under control of the Department of Public Works.

All projects for improving waterways and for protecting adjacent lands and properties from damage due to shifting river channels or to overflow in times of flood, originated by persons, corporations, communities or municipalities, must be submitted to the Secretary of the Department of Public Works and receive his approval before any of the work contemplated in the project is entered upon.

Where projects dependent upon Federal cooperation and financial aid are presented, the extent of that cooperation and the measure of financial aid must be passed upon by the Secretary of the Department of Public Works and he must submit his conclusions and recommendations to Congress.

The execution of any and all projects in which the Government cooperates shall be under the direction and control of the Department of Public Works.

The transfer of the several bureaus or departments now engaged in carrying on the various classes of work which it is the purpose of this act to place under the control of the Department of Public Works shall be made in such manner as not to hinder or retard any necessary work now in progress; but the transfer shall be made as speedily as is consistent with this requirement and all such transfers shall be completed within one year from the date of the passage of this act.

To defray the expense of organizing the Department of Public Works of the United States and to maintain the same until the Secretary submits the first budget setting forth the needs of the Department, the sum of Five Hundred Thousand ($500 000)

Dollars is hereby appropriated which shall be paid out of the treasury of the United States upon warrants drawn by the Secretary of the Department of Public Works.

Not only did I present this bill to the Third Annual Convention of the National Drainage Congress, but I sent a copy to President Wilson. Also I presented copies to our Secretary of State, to our Secretary of Interior and to certain of our National legislators. I received an acknowledgment from the President through his Secretary. I talked with Secretary Bryan about it and he expressed the view that it would come at some future time, but that I would not live to see it. The Secretary of Interior, Mr. Lane, was most sympathetic and friendly to the idea. Senator Ramsdell expressed his approval of the bill, but told me that unless I could get the country back of it, Congress would never touch it.

How can a lone Civil Engineer ever get the great American people to back up a proposition like this? Never can he accomplish it unless he can enlist great organizations like the Engineers Society of Western Pennsylvania in a crusade to bring it about.

Men, of this great society, let me tell you why I think a National Department of Public Works is needed.

This great nation of ours finds out gradually what it needs. In its very genesis, it knew it needed a Department of State, for young as it was, it had to deal with the nations of the earth. It knew it needed a War Department, for it had by war won its way to independence and a place among earth's governments. It knew it needed a Treasury Department, for it must collect and disburse revenues, issue a medium of exchange and protect the country's credit. It knew it had to have a Department of Law, presided over by an Attorney General, for it had to know and keep within the bounds of international law and to deal with interstate law affecting the interests of its citizens and those of the stranger within its gates.

Those were the four original departments having Cabinet representation.

The need for a Navy Department was manifest for a Navy had to be built up and maintained to protect its maritime commerce and to uphold upon the high seas the honor of its flag but the demand for this was not met until 1798.

A post office organization was kept up for thirty-five years before it was made a national department whose executive head was given a place in the Cabinet. This came to pass in 1828.

Its vast territory and the care of its wards, the aborigines called for the exercise of particular and responsible supervision and this call was met by the creation, in 1849, of the Department of Interior.

As time went by other needs developed; since from the soil comes man's sustinence and wealth, just recognition of its importance was made by the creation in 1889 of the Department of Agriculture.

The growth of one hundred and fourteen years demonstrated the need of a Department of Commerce and Labor and it was created in 1903. March 4th, 1913, Commerce and Labor were segregated and now we have the Department of Commerce and the Department of Labor.

The heads of all these Departments are members of the President's official family; they are his Cabinet advisers.

And now "in the fullness of time" another national need is recognized and its supply should not long be delayed. The need is for a National Department of Public Works.

The public works of the United States are vast in their scope and of immense importance. Some of the things that ought to be done are in process of accomplishment but they are few in comparison to the needs of a land whose material advancement is held back because needed work along many lines is not even attempted. The work that is being done is not concentrated in one department under one responsible head but apportioned off to several departments whose responsibilities and whose efforts are not correlated. The Treasury Department has charge of public buildings. Is there any correlation between scientific finance and scientific building? Does the training which fits a man to be at the head of the National Finances also fit him to pass upon architectural design and structural sufficiency?

The work of reclaiming arid lands, involving as it does vast engineering structures, is confided to the Department of Interior as is the research work conducted by the Geological Survey. The Department of Agriculture is charged with the engineering involved in drainage investigations and road building. The War Department has charge of the National defenses as is eminently proper; there is the appropriate field for the military engineer. But it also has charge of all the rivers and harbors of the United States and its acquired territory, together with the building of all canals, the cost of which is defrayed by the nation.

Now these activities are carried on by the several departments named, each independent of the other, without correlation or cooperation and it ought not to be so. These activities should all be aggregated in one Department under one responsible head who should be a member of the President's Cabinet and the peer of his fellow members.

Then, and not until then, will proper plans, upon broad and comprehensive lines, be worked out and carried persistently to a conclusion which will give results commensurate with the public need and worth the vast expenditure of the people's money.

What we need is a plan big enough to compass the land and so well considered that the work most needed can be first begun and when it is finished, it will be so much accomplished in the development of the great comprehensive project; and so let each successive component section of the plan be taken up in the order of its need until the last section is reached and the mighty work stands complete; a monument to the brains that planned and the energy, skill and well applied labor that accomplished all. Such a work as this is not for a decade or a life time but to be carried forward long after its designers have been gathered to their fathers.

But it is not necessary to fold our national hands and wait until this vast plan is all worked out and presented to the Nation. There are things to be done *now,* so obvious and so necessary that they are at once recognized as integral parts of any great comprehensive plan.

The vastness of the land suggests the immensity of the plan which must be evolved to meet its needs. The continental holdings of the United States, including Alaska, are given as 3 742 583 square miles. Within the United States proper, there are 26 410 miles of navigable rivers, 75 000 square miles of swamp lands and 1 200 000 square miles of arid lands. The entire coast line of continental United States and its insular possessions is given as 48 881 miles. *There* is a field of operations which must arouse patriotism and stir ambition. These rivers must be improved and made more useful to the commerce of the land. They must be given a capacity adequate to carry the floods which vast water sheds pour into them, or where possible, the intensity of these floods must be abated by partial storage in reservoirs which will give up their stored waters when stream conditions render it safe to release them; that release being subject to judicious control. And, wherever possible, these streams must be made to yield all the power that head and volume of flow can generate.

These 75 000 square miles of swamps must be recovered; the soil wealth which has been accumulating for "time out of mind" must be taken from the frogs and the reptiles and given to man for tillage with an assurance that no "garden of the Lord" ever yielded a richer bounty. Those 1 200 000 square miles of arid lands must be made to fulfill the prophecy of Isaiah "the desert shall blossom as the rose." For the sons of America will need all of these lands as the 100 000 000 of today will be 200-000 000 at no far distant tomorrow, and the increase will go on until there is no place in the whole land without inhabitant. Is it too soon to begin doing all of these things with energy and zeal? We know that the delay has been too long already. And yet our law makers hang back.

In what I am about to say I wish to make clear in advance that my remarks are not actuated by hostility to the United States Engineer Corps, for every citizen of the United States must be proud of the record these men have made and admire the integrity of an organization which has been a distinguishing characteristic of these splendid men. I speak more particularly of them because the horizon of their work is only bounded by the horizon of the Country that they serve.

For more than thirty years I have been in contact with the men of the Corps of United States Engineers and I know their virtues, which are many, and their failings which are few; failings theirs by reason of their humanity and not because of their training. I have throughout these years been on the opposite side of nearly every question which has brought me in contact with them and as a result I have learned to love these my *constructive* enemies. I have found them firm in their convictions, though, from my standpoint, often narrow in their views, loyal to their duty and their corps and honorable in their dealings. I fault not their efficiency, but their numerical inadequacy.

I find in "Form 87, War Department, Office of Chief of Engineers, Washington, January, 1916" a statement showing the rank, duties, and address of the officers of the Corps of Engineers, U. S. Army, that there are but 232 engineers of that corps in active service. Of these, eleven are in the Philippines, four in Hawaii, ten on the Panama Canal and twelve are detailed as instructors and two are on Legation duty. This leaves 193 men and of that number 64 are First Lieutenants and 28 Second Lieutenants; now lieutenants are about as capable of taking charge of public works as are the young graduates from our engineering universities and he would be truly confiding who would trust one of these fledglings with an important piece of construction; so that the available U. S. Engineer Corps is whittled down to one hundred and one experienced men and from that number must be subtracted the men whose duties are connected with the office of the Chief of Engineers and the War College in Washington. The distinguished remainder can not cope with the requirements of 26 410 miles of interior waterways, 48 881 miles of sea coast, national fortifications, government canals and miscellaneous work. These works must go on and the numerical deficiency must be made up from the ranks of the civilian engineers. The natural, the inevitable, result is that the engineering of the United States is mainly done by civilian engineers. The military engineer too often becomes an executive officer, affixing his signature, pro forma, to plans in the preparation of which he has had very little hand.

In the thirty-six years that I have lived in Chicago, there have been ten United States Engineers in charge of the work of that district, one of these W. L. Marshall, later justly honored as Chief of Engineers, was in charge of the Chicago District for eleven years, and during all of that time there has been but one civilian assistant engineer in subordinate charge. About the time that an engineer officer has been inducted by his civil assistant into his duties and really becomes master of conditions and cognizant of the needs of a district, he is—like the Methodist minister—moved to a new field of duty.

Nor is this the worst of it. Genius in the United States Engineer Corps is cramped and initiative is repressed, these men must not originate; they may and do recognize needs in the Districts to which they are assigned but suggestions are not welcomed in Washington. Until Congress orders investigations and reports, the army engineer may not ascertain facts (or if he does, he must keep them to himself) nor report conclusions. All of this reacts upon the civilian assistants; they become routine men, doing what they are told faithfully and well, but they soon part with all idea of initiative.

The natural result of this shortage of United States Engineers is delay in carrying on work which they are called upon to perform—in addition to regular duties—as members of Engineering Commissions. I will make a citation or two in support of this statement and I wish it distinctly understood that I have no thought of censure for the men who compose the commission of which I speak.

In 1902, Congress ordered surveys, estimates and a report on a fourteen foot waterway from Chicago to St. Louis and provided $200 000 to defray the cost of it. The Commission to whom this work was intrusted was composed of distinguished engineer officers. They employed parties of civilian engineers, in direct charge of a civilian engineer, and put them into the field to ascertain the facts. The surveys were made; the data thus secured was compiled and maps and profiles based thereon were prepared. The Commission made its report in 1905 showing that the project was practicable; but, that in the judgment of the Commission, there was no commercial justification for the building of the waterway. Later, for some reason, Congress called for another report on this same waterway extended to Cairo and a Board was formed composed of four military engineers and one civilian. This Board had for its use all of the information secured by the previous Board at a cost of $200 000 and all of the information collected by the Mississippi River Commission. It began its work in November, 1910. The report made by the Board in February, 1911, as is shown by the last paragraph thereof, was not final and certain features upon which it was required to report were not then covered. The final report of this Commission was transmitted to Congress by the Secretary of War February 18th, 1914, and became H. R. Doc. 762, 63rd Congress, 2nd Session. Why this delay of three years? Presumably because the members of that Commission were so burdened with their regular duties that they had not time to bestow upon this super added requirement. They were busy men and the things which *had to be done they did* and left the matters which could wait until they could get around to them.

There are two features of the suggested bill that seem to me to be of especial importance; first, the appointment of a Commissioner of Public Works, "who shall be a man of recognized ability and successful accomplishment along lines of engineering science and construction * * *. The man so appointed shall hold office until disqualified by physical or mental infirmity, old age, moral delinquency or demonstrated unfitness." Next, that requirement that the "Secretary of the Department, with the approval of the President, shall present to Congress at each Session such projects as he deems meritorious and for which there seems to be an urgent need, together with estimates of cost and his recommendations thereon."

The carrying out of this requirement would serve to correct an abuse which has led to scandal and waste. No project for a public improvement can now be reported on unless Congress orders it and getting Congress to order such a report becomes the task of the interests locally concerned in the improvement. These interests must secure influence sufficient to get their project a hearing and this makes business for lobbyists and gives the local Congressman a chance to make political capital by boosting the game. With such a department as is here advocated and such a requirement in the law creating it, a broad view of the whole national estate would be taken and the needs of every section of the country would be impartially presented upon the basis of merit and not of political expediency.

Once more our Country faces troublous times, invasion has crossed our Southern borders with torch and murder, giving a glimpse only of the Hell which *is War*. This incident was like the opening of a furnace door, revealing the horrid glow of the heat within; a heat which has been consuming the vitals of Mexico for 5 long years. Our troops have entered that furnace, they will be tried by its fires, and the awful question arises, will they quench those fires or be consumed by them?

Men of vision have long been calling upon our people to prepare. "The Battle Cry of Peace" has resounded through the land, but it had a far off sound, as impersonal as the voices we hear in dreams. The desperate venture of an outlaw, with his cut throat followers, has dispelled the unreality of the dream, and made the whole land feel that the time for action has come. That the men of our land must "be up and doing with a heart for any fate." Suppose that the marauding band of Villa had been the advance guard of a great military power; a phalanx and not a flying squadron. How far by this time would that entering wedge have forced its way toward the heart of our country, driven by the maul of a supporting army, equipped with all of the modern enginery of war? That blow was struck on March 9th and not until March 15th was the military arm of the richest nation on earth able to stretch across the border into the fastnesses from which came the stroke that fell upon Columbus. The United States had the skeleton of an army on the Mexican border and it took seven days to clothe that skeleton with strength enough to pursue two thousand bandits into the wilds from whence they came. We have men; millions of men; but—borrowing the exclamation from a great orator—"men are not soldiers!" Men are the material from which soldiers are made. Ore is the material from which great guns are made, but the ore must pass through the furnace and from the furnace through all of the processes which intervene between the smelter and the steel ingot; and the steel ingot must be wrought and fashioned through the successive operations of the machine shop until at last it emerges an engine of war ready to hurl missiles of destruction against the foe. So men, the raw material from which soldiers are made, must pass through the mill; beginning with the awkward squad and so on through all of the processes of drill and discipline until they are ready to go in the firing line, not as units but as integral parts of a great fighting machine.

Am I digressing? What has preparedness to do with National Department of Public Works?

A National Department has much very much to do with National preparedness. It takes men trained in the science of war to build a country's defensive works. It takes men learned in the science of war to teach and so train the man from civil life that he may be a competent defender of his country. Our country lacks, woefully lacks, men so taught that they can teach others the art of defense; the use of arms, the construction of strongholds. The Military Mill at West Point grinds slowly and turns out too few educated soldiers for our Country's needs; therefore, the grist which comes from that mill should be wholly available for the work of defense and of educating defenders.

The Army list for February 1916 gives 232 members of the United States Engineer Corps.

Had we a National Department of Public Works, the duties now imposed upon the Military Engineers would be in the hands of Civil Engineers and the military men could be rendering their Country that expert service which their country needs and for which it has educated them at great cost.

Thus we see the connection between a National Department of Public Works and our National defense.

A National Department would make for National Security, National Efficiency, National Economy, and National development, along comprehensive lines.

Members of the Engineering Society of Western Pennsylvania, have I convinced you? If I have, carry your convictions outside of your own organization and do not think of a National Department of Public Works as a means of advancing the interests of ourselves and our profession, but as a patriotic effort to build the prosperity of our Country upon a base broader and more deeply laid than has heretofore been done.

DISCUSSION

Mr. Morris Knowles:* The speaker is much interested in this subject and believes the Society is to be congratulated that we have had the opportunity to hear so important a subject discussed by a man who can treat it so well with abundant experience, and who has thought about it so long as has the author.

The subject is not entirely new to the speaker, having had the pleasure of serving on a Committee on Resolutions at the meeting in St. Louis to which reference has been made, when this bill was first brought to the attention of some people in this country. As Mr. Randolph will remember, at that time I felt constrained to oppose the measure for the particular purpose of the conference and at that particular time, for reasons which were apparent but which did not relate to the merits of the measure at all but only as to the time and occasion.

The speaker is glad, therefore, to have this opportunity to record his unqualified approval of the measure, and to express the belief that it is the kind of measure that the country should undertake. It represents the type of activity particularly in which engineers should interest themselves,—because we above all others have the chance to realize, what the public which pays the bills does not realize, what it means to dissipate the energies of the country so badly as they are at the present time by having activities of a similar nature conducted by so many different departments and so many different bureaus.

We very badly need some sort of agency which will correlate these agencies. It seems foolish, for instance, that the subject of which hydraulics in its many ramifications should be studied by the Weather Bureau in the Department of Agriculture, somewhat by the Geological Survey, in the Interior Department, and some provisions should be carried out by the Light House Bureau in the way of construction, some construction work by the army engineers of the War Department and some by the Bureau of Yards and Docks, of the Navy Department, etc. The illustrations can be multiplied. If all such agencies could be brought together it

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would be a vast saving in money and a vast saving in time and a vast saving in effort.

The regulation of the rivers is of course a subject near to my heart. Mr. Randolph has covered that very thoroughly, but I would like to add a few words. We are just coming to realize by the slow process of education,—but it will still continue to be a long process of education before it is fully realized,—that the constructive works upon the rivers of the country should be predicated upon not only the navigation (that on which they now seem to be based largely) but also upon other uses of the running water. We must understand that running water, well regulated, has many useful purposes for mankind. And only when we do so realize that these uses and benefits can be obtained will we approach making the river serve that great and fundamental duty which Gibbon so beautifully wrote about in his Fall of the Roman Empire; commenting that Rome had failed in the regulation of the River Tiber and its tributaries.

We are just beginning to interpret what has been done in other countries. And strange as it may seem, in these days when so many things are before the National Congress, we find appearing more and more those measures with regard to this complete regulation and complete usefulness of the streams of the country. Not only is it appearing in those types of legislation which have been talked so long time, such as financial and rate regulation for water power projects, but also in the proposed laws for the regulations of streams so that floods shall not prevail. And we find that Congressmen are thinking as they never did before that it is only when we think of the streams as an entirety from the source to the mouth that we come to approach that greatly desired thing which it is so important to obtain, namely, to have a stream regulated so that we will not have floods, and we will have water when we need it for navigation and for power and water supply and sanitary conditions and irrigation, and so on.

And we find that Congressional Committee considering very strongly today, the necessary machinery; this very thing of a Department of Public Works, such as Mr. Randolph has brought out; so that all these works shall come under one large department and then we shall not have this division of authority. Nor will we have this suggestion that if we are going to build any national public work on our rivers, it must come under the Commerce Act and therefore must relate to navigation or the War Department or any one of half a dozen other subdivisions of authority. We have clauses in the Constitution of the United States which should be sufficient authority for doing these other things which have been carried on so thoroughly and successfully in the central European countries, where the National Government has been the agency to control and spend the money and receive contributions from local communities, manufacturing and other concerns.

Mr. Randolph has well covered the subject by illustrations as to why we cannot expect, except under unusual circumstances, from a body of men, however well the personnel may be constituted, who are limited in number and have as their one actuating motive, both by education and training, another line of duty; the successful carrying out of large public works. He has shown us very thoroughly why it should not be expected that they would think of all these other uses of flowing water, nor will these other uses be as near to their hearts as the one with which they are especially concerned. Certainly in these days, when preparedness is so vividly before us and there is such great need for training chosen men, where is certainly opportunity that these other needs of public life shall be considered and prepared for as well and that we shall have organized one central coordinating agency which will take care of them. It has been a great pleasure to hear this paper and I wish to commend Mr. Randolph for presenting it at this time and thank him for giving this Society the opportunity of listening to it.

Mr. Burd S. Patterson:* It occurred to me while Mr. Randolph was speaking about the great demands upon the army engineers and the limited time they have to expend upon those services, that when we were considering the selection of an engineer to consult with the Lake Erie & Ohio River Canal Board, the question came up of getting an army engineer. Ex-Mayor Magee, the former president of the Board, gave us this experience. He said he would not be able to get any engineer of a high rank whose name would be known to the people generally and which would inspire confidence. He wanted something done and his Board tried to get such an officer and after many months of effort, pulling all sorts of wires, the Board succeeded in getting a captain of the engineering service assigned to this particular work. The Board collected all the evidence it had on the subject and the officer studied the question for one day and made a report on it, which was all the time he was able to give to it. That illustrates one of the points the speaker made.

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*Of Lake Erie and Ohio River Ship Canal Board, Pittsburgh.

Then I heard Governor Dunne, of Illinois, at the Rivers and Harbors Congress last summer tell how they were trying to put through a water way and extend the drainage canal to the Mississippi River. They had voted the money and had the land, but they needed some report and approval from the U. S. Engineers. He stated "We have been down here for the better part of a year trying to get permission to build this waterway upon our own land with our own money and everybody is so busy that we cannot get anybody assigned to that work".

Another case of which I heard in conversation at noon today with one of your honored members, Mr. E. K. Morse, illustrated that while the U. S. engineers are of the finest character, yet they are hampered by their traditions and by the courtesy they think they owe to their fellow members, so that they do not like to make a report against anybody else belonging to their corps, particularly a superior officer. Mr. Morse said a number of years ago they had a board of engineers to look at some harbor lines here. One of them looked at the river banks and said: "These harbor lines are all wrong, they ought to be corrected." That was in the morning. That afternoon, that man voted not to change the harbor lines, and when asked why it was that in the morning he said the lines were wrong and in the afternoon he would not change them, he said that he did not know the matter had previously been considered by army officers and they had found the other way.

I am not an engineer, though I started in to be an engineer by carrying a chain in the anthracite coal region for a while. But Mr. Randolph was a member of the board which passed upon the type of the Panama Canal and he was one of the five members who finally decided on the lock canal instead of the sea level canal.

He told me that the foreign engineers were all in favor of the sea level canal and it was found out afterwards that the reason they were in favor of that plan was not on the merits of the case so much as on account of the fact that they thought the President of the United States wanted a sea level canal and it would be committing *lese majesty* if they found against the wishes of the President of the United States. But Mr. Randolph and several other civil engineers on the commission fortunately were not hidebound by tradition or hampered by an awe of rank and hence made a minority report, which was finally accepted by the President and Congress resulting in the construction of the canal on its present lines, which are now generally conceded to be correct.

MR. ISHAM RANDOLPH: Might I explain how that was? Before we went to Panama the President sent for us and gave us a talk. He gave good reasons for wanting a sea level canal, but he said: "What I ask you is not to tell me what you think I want, but what I ought to want." The foreigners were tremendously impressed by it. And the chief engineer of the Manchester ship canal kept accusing us of disloyalty for not agreeing to it at once, until I got tired of it and I said "Mr. Chairman, I object to taking up the time of this commission with irrelevant discussion. It is so often cast in our teeth that we are disloyal to our President that I cannot let it pass another time. The gentleman has breathed the free air of America for too short a time to appreciate the genius of our institutions, he does not realize that we have no sovereign; that we are a sovereign people. We have a President who spoke to us in no uncertain terms and told us he wanted a sea level canal but he also said, "What I ask you of is not to tell me what you think I want to know; but what in your judgment as honest men I ought to know." We propose to tell him what he ought to know.

MR. D. W. MCNAUGHER:* I am very glad to be present to hear this paper. I have known of Mr. Randolph's work for the past thirty years and what he proposes now will not be the least of his accomplishments if he succeeds in his purpose. There is no person in this room who should not take the statements as axioms.

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*Of Robert W. Hunt & Co., Pittsburgh.

What is needed is to have this question taken up properly with the public. All politicians will be against it, but if this can be published and advertised and brought before scientific societies first, and then through the newspapers to the general public, I think the country will be impressed with the necessity of it. There is no doubt that we have a great many good engineers in the U. S. Engineer Corps, but I believe there are more good engineers outside the U. S. Engineer Corps because we have a greater number of engineers in civil life and they give their thought, not to the public questions entering into any construction, but to the necessity of that construction and the best method of that construction.

A Department of Public Works as Mr. Randolph states it and as has been carried out in foreign countries, would, in my opinion, be the very best thing for this country. I am glad Mr. Randolph brought this subject up and I hope he will have all success in getting it before scientific societies and through them to the public.

MR. F. W. H. CLAY:* My excuse for taking up the time of the Society is that I have personally seen the workings of some of the Government's engineering bureaus, by having worked some six months in the Geological Survey, six months on the Mississippi River Commission, and several years in the Coast Survey. Some of the remarks reminded me of an incident further illustrating the isolated situation of the army engineer. The hydrographic party I was in in 1894 got word of a report that a shoal had formed off the South pass of the Mississippi, and we were hunting for it unsuccessfully for about a week. During that time I overheard an old army engineer say, "I told you so; I knew all along that these shoals would form there." You will probably remember that the famous Captain Eads suggested the method of dredging out the South pass; that is, the scheme of stopping some of the mouths of the river to increase the current through the South pass, and let it dig out the channel by attrition, which it immediately did. There had been a great controversy between army engineers and civil engineers about the feasibility of the plan, the theory of the army engineers being that the silt brought down by the river would continuously form shoals off the mouth of the pass. Here, many years after proof of the success of the civil engineer's plan, was an army engineer eagerly seizing upon a possible proof that he was justified in saying "I told you so."

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*Patent Attorney, Frick Annex, Pittsburgh.

Coming to the paper itself, I am sure we were all very much impressed not only with the importance of it, but with its timeliness. It suggests a remedy for many evils. One virtue of the Army Engineer Corps is that it *has* traditions and fixed policy. That is at the same time its strength and also its weakness. It makes the administrative work efficient, though it retards improvement. At Panama the army engineers had a tradition, an *esprit de corps,* a continuity of policy, which other groups of engineers do not have because they have not been long associated. The paper makes a valuable suggestion of a scheme of getting the *esprit de corps* of the Army Engineers with the larger experience in life, and continually bringing into the Corps new ideas so that the whole group will at the same time have efficiency and progress.

In any discussion of this scheme it seems to me it would be well to point out the difficulties in the way. As we are now situated, there are I believe ten departments of the executive branch of the government, and all except the Department of State and the Attorney General's Office have some form of engineering work to do. For example, the Coast Survey and the Supervising Architect's Office are under the Treasury department; the Geological Survey, the Land Bureau, Bureau of Mining, etc. are in the Interior department; the Agricultural department has the Weather Bureau, and I believe drainage and roads, while the Lighthouse Bureau and Life Saving Service are in the Commerce department, and so on. Again, several Departments have several Bureaus with work having no relevance, and others have work in no wise related to its primary function. For example, it would be difficult to give any valid reason for having the Coast Survey in the Treasury department.

But when we contemplate the change, the immensity of the proposition rather appals me. To have all such works as the Coast Survey, Geological Survey, Weather Bureau, River Commissions, Lighthouse Board, Bureau of Harbors and Docks and Yards in one department, would be a tremendous and perhaps unwieldy department quite overtopping and probably interfering with the other departments.

Has Mr. Randolph thought of a possible division of labor between investigations on the one hand, and constructive works on the other? For example, the Geological Survey has very little constructive work, and moreover is engaged in work of very general interest, and unconnected with such work as digging canals. Again, the Department of Agriculture has such institutions as the Weather Bureau, which are purely investigating bureaus unconnected with any constructive engineering, and of very general interest. Would there not be a possibility of making a division between the constructive works and the purely investigating bureaus, leaving the latter where they now are? One other difficulty to be always remembered is that the larger part of the constructive engineering works is primarily beneficial to one locality, and a general policy of appropriation would be very difficult to attain.

I do not like to miss this opportunity to make one other suggestion which is in line with the matter now of most interest to the public. War has become in these modern days almost purely an engineering proposition. There is no longer any real sharp line of distinction between the military engineer and the civil engineer, or for that matter the mechanical or electrical engineer. The military branch of the government must be run by all kinds of engineers. The profession of arms is really an engineering profession, purely. But it is useless except in war time. I was talking the other day with a Congressman much interested in enlarging the army, and he said that the principal difficulty in getting enlistments was that the average American does not like the idea of an useless existence; that the army is purely an emergency instrument, and in ordinary times has nothing to do which is immediately and obviously useful; that if some way could be devised by which a soldier would have all the time some useful occupation, it would not only enlarge the usefulness and work economy in the army, but it would greatly encourage enlistments. Suppose for example that we had enough men, why couldn't the soldiers have furnished all the labor used in digging the Panama Canal? What is the difference between digging practice trenches across a hill for training, and digging trenches at Panama where they are of lasting use? When we think of the rivers and canals requiring work, the drainage of swamps, the irrigation of deserts, the planting and care of forests, the construction and keeping of harbors and docks, it seems to me easily possible that a large army might be so organized as to constitute in times of peace merely a large engineering expedition, and simultaneously work in all the military drill necessary. As the genius of our people is unalterably against any pure militarism, it may be that in this direction would lie the solution of both the difficulties of getting a trained army and of enlarging and making more efficient the engineering work of the nation.

Mr. Isham Randolph: The work of the army engineers has been a credit to their corps and a credit to the United States. The principal engineers have had their work recognized. They have been made;—one a Major General, and two, Brigadier Generals. There was a civil engineer who had as difficult work as any man on the Isthmus, the Pacific Division, Mr. Williamson, and he performed that work as efficiently and as successfully and more economically than the army engineers, yet he has had no recognition whatever. He has never been mentioned in connection with the work, and it is a matter of record that can be established from the reports of the Panama Commission that his work was done more economically than any other division.

Mr. Warren E. Emley:* As an engineer at present in the employ of the U. S. Government I would like to correct a few statements which I believe have been misleading. There is at the present time a great deal of correlation and cooperation among the various bureaus. We cooperate so far that we do tread on each others toes occasionally, but that has not been a serious matter. It would be of some advantage if all of this work could be gotten together under one department but so far as I am familiar with the work and as my experience goes I can not see that the advantage will be so very great. For instance take a concrete case. Supposing the government wants to build a postoffice. First they send a geological survey man out to look up the building materials, the site having been selected by the Post Office Department. Then the supervising architect of the Treasury Department draws plans and specifications, and the materials in the field

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are sent to the Bureau of Standards to be tested. Finally the Bureau of Erection does the work. There are four Bureaus and four different Departments which have all had to do with the building of that postoffice. Those bureaus all act in cooperation. There is no friction of any kind whatsoever. I can not see exactly how that could be improved even if all those bureaus were in one department. I am employed by the Bureau of Standards in the Department of Commerce and I know I am a great deal better acquainted with members of other bureaus in other departments than I am with members of other bureaus of my own department. For instance in the Department of Commerce there is a Bureau of Foreign and Domestic Commerce, a Bureau of Light Houses and several other bureaus of which I know not a single member, whereas I am in almost daily contact with members of the Geological Survey and the Bureau of Mines and other men of the Department of the Interior and the Post Office and Treasury Departments.

Mr. A. Stucki:[*] What I have heard tonight has many times paid me for coming to this meeting, and I feel that some day we will have a Department of Public Works. It is true, the letters Mr. Randolph spoke about may have been very discouraging, but on the other hand, let us not forget that it took many years before the other departments, one by one, were established.

Mr. Isham Randolph:[†] I endeavored to make my argument for a National Department as conclusive as possible; but it is not within the compass of my ability to exhaust in one argument, or in many, the great possibilities embraced within this suggestion. It was gratifying to me that my listeners seemed, with one exception, so entirely in accord with the purpose which prompted my argument. It takes exceptions to prove rules and Mr. Warren E. Emley offered the proof in his remarks.

He cited most pleasing instances of cooperation between men holding their commissions from different Government bureaus. These instances served to show that where good sense and good feeling—a common desire to work for the common good—pre-

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[*] Consulting Engineer, Oliver Building, Pittsburgh.
[†] Author's closure.

vail, the necessity for a centralized power which welds all efforts into the common purpose of united service, is less essential than my view would indicate. But that state of affairs is dependent upon a rather uncommon demonstration of good sense and freedom from petty jealousies, and human experience, so far, does not lead us to look upon such a state of affairs as natural or usual and I should like to see a vested authority harmonizing and controlling activities which under existing conditions can not be depended upon to collaborate to secure the best results for the Nation.

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THE EXTENT TO WHICH SEWAGE CAN BE PURIFIED BY PRACTICABLE METHODS OF ARTIFICIAL TREATMENT NOW IN USE

By HARRISON P. EDDY*

All of the fundamental principles of sewage disposal and treatment now available had been recognized and actually utilized 25 years ago. Coarse screening has been practiced at Boston since 1884, and the Massachusetts Metropolitan Sewerage Commission put the Deer Island submerged outlet into use in 1895 for the purpose of furnishing adequate dilution to the coarsely screened sewage from the northern portion of the Metropolitan District. Paris and Berlin have been applying their sewage to broad irrigation farms for more than 30 years; the Welsh town, Merthyr Tydvil, treated its sewage by intermittent sand filtration as long ago as 1871. Sedimentation was used in England many years ago, and in 1870 chemical precipitation was well established there. Over 25 years ago Webster had invented an electrical method in which the suspended matter was precipitated by a process closely akin to chemical precipitation, and combining therewith, at least in principle, the killing of organisms, or disinfection.

The fact that these principles were known and applied a generation ago is seldom recalled by those at work upon similar problems today. The progress of the last 25 years has been in acquiring a correct perspective of the problems of sewage disposal, a better understanding of the principles upon which the processes of sewage treatment are based, and in perfecting such processes and the means of applying them. Much progress has been made along these lines, and there are now a number of modifications of each of the fundamental processes in use a quarter century ago.

It should not be inferred from the foregoing that little real progress has been made during this time, for this is not the case. Marked improvement has been made in screens, particularly those intended for the removal of the finer suspended particles. The laws affecting sedimentation are better applied, the most radical and important changes being those due to the theories that the period of retention in tanks should be reduced to a minimum consistent with efficiency in removal of those solids capable of settling in a reasonable length of time and that the settled solids should be promptly removed from contact with the partially clarified sewage. The greatest advance in the art has been the development of the process of bacterial oxidation by means of surface contact in bacteria beds. This process, as applied in intermittent filtration through sand, was comparatively well known 25 years ago, but the difficulties resulting from lack of suitable natural sand deposits led to the discovery of means of using other material, such as cinders and broken stone, by devices known as contact beds and trickling filters. These two methods, although involving substantially the same principles as intermittent filtration, generally accomplish much different results and have proved to be substantial aids in the solution of the sewage treatment problem in many places. Disinfection has made distinct advance and whereas it was hardly more than an experiment 25 years ago, its value for safeguarding water supplies and shellfish layings has now been demonstrated.

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*Of Metcalf & Eddy, Consulting Engineers, Boston, Mass.

At the present time we are just over the threshold of a newly discovered process known as the activated sludge treatment. While the fundamental principles upon which it depends may not have been fully ascertained, the information available indicates that they are substantially the same as those of the processes now used.

COMPOSITION OF SEWAGE

In order to consider intelligently the several available methods of sewage treatment and their relation one to another, it is necessary to obtain a clear understanding of the general ingredients of sewage.

The physical condition of the principal constituents of a hypothetical sewage of medium strength are shown in diagrammatic form by Fig. 1*. It should be noted that in this illustration there

*American Sewerage Practice, Vol. III, p. 200.

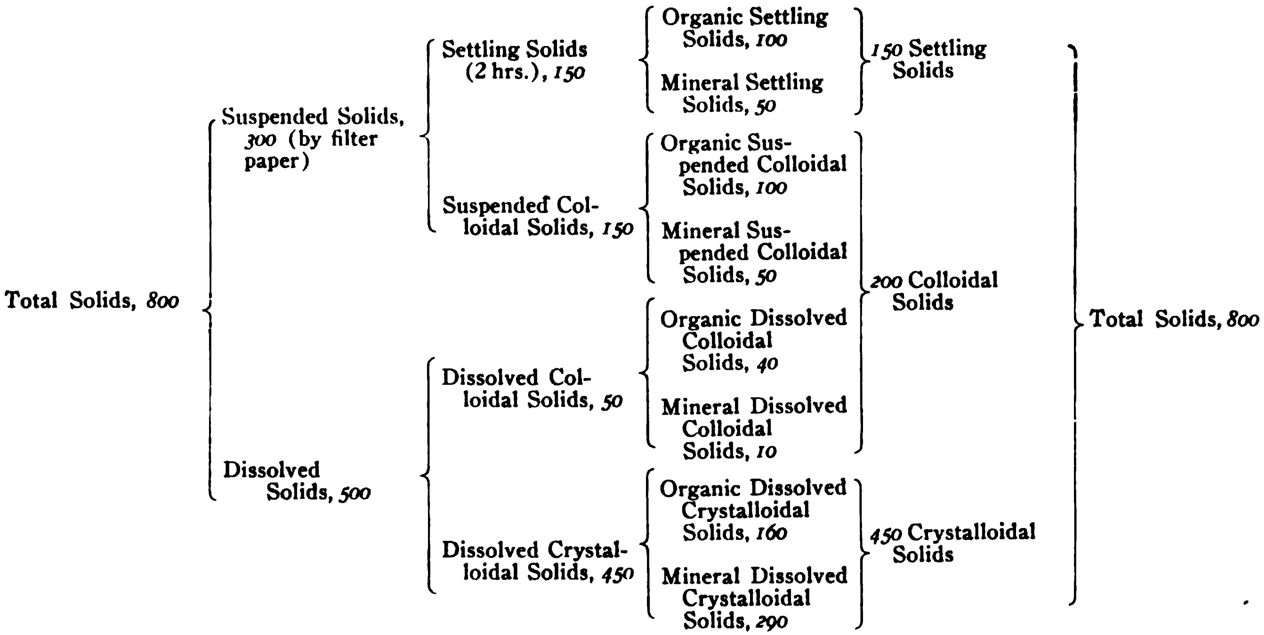

Total Solids, 800
Suspended Solids, 300 (by filter paper)
Dissolved Solids, 500
Settling Solids (2 hrs.), 150
Suspended Col-loidal Solids, 150
Dissolved Col-loidal Solids, 50
Dissolved Crystal-loidal Solids, 450
Organic Settling Solids, 100
Mineral Settling Solids, 50
Organic Sus-pended Colloidal Solids, 100
Mineral Sus-pended Colloidal Solids, 50
Organic Dissolved Colloidal Solids, 40
Mineral Dissolved Colloidal Solids, 10
Organic Dissolved Crystalloidal Solids, 160
Mineral Dissolved Crystalloidal Solids, 290
150 Settling Solids
200 Colloidal Solids
450 Crystalloidal Solids
Total Solids, 800

Fig. 1. Physical Condition of Principal Constituents of Sewage of Medium Strength (Parts per Million).

Note: The suspended solids include all substances retained upon ordinary laboratory filter paper. "Dissolved" colloids is a term coined to apply to substances which will readily pass through the filter paper but which are colloidal.

are three classes of substances—suspended, colloidal and crystalloidal. The first and second of these can be removed physically without change in composition, while crystalloids are dissolved and must be changed in chemical composition before they can be removed or altered in character. It will also be seen that 400 parts per million are organic and 400 parts are inorganic or mineral. The latter substances are not ordinarily capable of producing putrefactive conditions, and the problem of sewage disposal is concerned almost wholly with the organic matter. This is disposed as follows:

Settling solids	100	parts
Suspended colloids	100	"
Dissolved colloids	40	"
Crystalloids (dissolved)	160	"
Total	400	"

The settling and colloidal substances, therefore, constitute 60 percent and the dissolved crystalloids but 40 percent of the total organic matter.

Where sewage is deprived of its objectionable characteristics by artificial treatment, one or both of two fundamentally different processes are generally employed; first, the actual removal, or taking out of the sewage, of certain constituent parts, as, for example, such substances as paper, corks and garbage which may be removed by screens; second, the conversion of putrescible organic matter into stable substances. The former class of constituents is confined primarily to the suspended matter, while the latter comprises both suspended and dissolved substances.

DILUTION

All sewage must ultimately reach natural streams or bodies of water. When the quantity of sewage is small in comparison to that of the body of water into which it is discharged, sewers are usually designed to empty their contents directly into it, without previous treatment. Under such conditions the waters are able to assimilate the organic sewage matter, a process constantly going on in nature.

The velocity of a flowing stream may be a very important factor in the disposal of sewage by dilution, for it may thus be enabled to convey the suspended and dissolved sewage matter to a large body of water where ample dilution is afforded, in so short a period of time that the ill effects of the admixture of sewage with even a relatively small quantity of river water, may not become evident.

In general, however, the sewage matter must be changed from its natural putrescible condition, either into inoccuous mineral substances or into other matters which are organic in nature, but relatively stable, so that they cannot be the cause of putrefaction. Such a change is brought about through the agency of living organisms, the most numerous and probably the most potent of which, in the majority of cases, are bacteria, although the microscopic organisms, such as various kinds of algae, are exceedingly important factors in the cycle through which the constituents of organic matter are continuously passing in Nature's process of transforming organic matter into mineral substances and these back again into organic matter.

It may be said safely, therefore, that practically the whole process of sewage oxidation in nature, appears to depend upon the micro-organisms. In artificial treatment, also, practically all methods involving oxidation of organic matter appear to depend upon living organisms and their products. So it is important to bear in mind that to secure effectiveness and efficiency it is necessary to create conditions favorable to the growth and reproduction of these minute organisms. Such conditions are provided by natural agencies when the relative proportion of sewage to diluting water is small. It is necessary to adopt artificial means only when the relative quantity of sewage becomes disproportionate to the capabilities of natural waters for its oxidation. Under these conditions the first step toward artificial control may be to create a more complete distribution of the sewage through the diluting waters, thus overcoming the effect of an overload due to the concentration of the sewage in a small portion of the diluting water. The advantage of this is often overlooked.

ARTIFICIAL MEANS OF SEWAGE TREATMENT

The objects of artificial treatment, with the methods by which they are attained, may be classified as follows:

A. To prevent waters into which sewage is discharged from becoming offensive to the eye on account of coarse floating and suspended matter.

Screening.
  (*a*) Coarse.
  (*b*) Fine.

B. To prevent such waters from becoming malodorous.
  1. Sedimentation.
    (*a*) Rapid in grit chambers.
    (*b*) Slow in settling basins.
      Plain.
      With septic action in single-story tanks.
      With sludge digestion in two-story tanks.
      With chemical precipitation.
      With electrolysis and chemical precipitation.
      With colloiders.
  2. Aeration, contact with the organisms or sludge from previously aerated sewage, and sedimentation.
  3. Contact bed treatment.
  4. Trickling filter treatment.
  5. Intermittent filtration.
  6. Broad irrigation.

C. To prevent the introduction into the water of germs of disease.
Disinfection.

The treatment of sewage may be accomplished by a single process in some cases, but usually it is effected by a series of steps, the degree of purification increasing with each successive stage. If raw sewage may be discharged into natural waters without creating objectionable conditions other than offending the sense of sight, the simple process of screening may suffice, but if it is necessary to remove more of the matters likely to settle, sedimentation may be adopted as an adjunct to or substitute for screening. Where the diluting waters are so limited in quantity that it is necessary to supplement their powers of oxidation, some method of artificial oxidation must be adopted; such, for example, as filtration through beds of sand or stone which form the habitat of bacteria and other organisms capable of bringing about the more or less complete and rapid oxidation of the organic matter of the sewage. Under still more exacting conditions it may be necessary to go further with the removal of pathogenic organisms. The final process would then be disinfection, through which a large proportion of the harmful bacteria may be eliminated even from settled sewage. In such a case the treatment would involve four successive steps, namely, screening, sedimentation, oxidation by filtration or other means, and disinfection.

SCREENING

Municipal sewage contains many relatively large and coarse substances such as cloth, paper, garbage and pieces of wood, which may interfere with pumping and other machinery and prove unsightly in the waters into which the sewage is discharged.

Such substances may be removed by coarse screens, which often consist simply of parallel iron bars, or gratings, set vertically or at an angle of from 30 to 60 degrees with the horizontal, through which the sewage flows and upon which the very coarsest of the suspended and floating matter is retained.

Coarse screens will remove only from 5 to 10 parts per million of suspended matter originally contained in the sewage. This is usually sufficient for the protection of machinery and is regarded as sufficient for all purposes in some cases where sewage is discharged into large quantities of diluting water, as into the tidal waters of Boston Harbor off Nut Island.

If, however, sewage is to be discharged in relatively large quantities into waters used for boating and other pleasure purposes, coarse screens cannot be relied upon to remove all of the suspended matters which are recognizable as being of sewage origin and which, therefore, may be considered as offensive to the sight. Where such substances must be removed and also where a somewhat greater reduction in the organic matter is required, fine screens may be used, either by themselves, or supplementary to the coarse screens. Numerous types of fine screens have been perfected and placed upon the market, among which may be mentioned the Weand screen, first installed at Reading, Pa.; the Jennings screen, used at the Union Stock Yards in Chicago; and the Riensch-Wurl screen used in Germany and being installed to a limited extent in this country. The Weand screen consists of a horizontal revolving drum covered with a fine mesh screen. The sewage is discharged into this drum at one end and flows out through the cloth, which retains the suspended matter until it is washed off into suitable receptacles by jets of water. The Jennings screen is of the moving band type, the lower end being submerged in the sewage, which flows through the screen cloth, which retains the suspended matter and carries it up out of the sewage. When the screen has passed over the pulleys at the top, the screenings are blown off into a pit by a jet of compressed air applied to the back side of the screen. The Riensch-Wurl screen which is typical of its class consists of a disk of perforated metal, with or without a frustum of a cone attached to its center, the whole being mounted on a shaft whose inclination from the vertical determines the degree of tilting of the disk. As the screenings are raised above the surface of the sewage by the revolving disk and cone they are swept into a circular gutter, by brushes on the ends of the arms of a large spider. Where the screen is surmounted by the frustum of a cone the side of the cone is cleaned by a brush inclined against its surface.

The quantity of suspended matter removed by fine screens varies with their efficiency and the quality of the sewage. Such screens may remove from 20 to 70 parts, averaging perhaps 50 parts per million of suspended solids.

SEDIMENTATION

It has been claimed sometimes that with the most effective fine screens the organic matter may be removed to such an extent as to greatly reduce the oxygen requirements of the sewage, and thus make it possible to dispose of a much greater quantity of screened than of raw sewage in a given quantity of diluting water. The concensus of opinion, however, appears to be that while the reduction of organic matter by fine screenings may be considerable, it will not be enough to greatly increase the quantity of sewage which a given stream or body of water may receive and remain in a satisfactory condition. Grounds for this opinion will be apparent when it is considered that much of the coarse suspended matter in sewage consists of materials like paper, matches and coffee grounds, which are relatively stable organic substances and which do not constitute so great a tax upon the diluting power of the water as equal quantities of fecal and other polluting substances which are more finely divided and consequently which are not so completely removed by screens. Therefore, where it is necessary to increase the quantity of sewage which may be discharged into a body of water, sedimentation in some form is generally adopted.

Grit Chambers: The grit chamber ordinarily is merely an adjunct to the main process of sewage treatment, its function being to remove the coarser sand and gravel commonly called grit, which might cause excessive wear of moving parts of machinery, or cause deposits in tanks or elsewhere which would prove more expensive to remove from such tanks than from grit chambers. There is much diversity in the design of such chambers, the older ones and those most commonly in use in England being so large that they permit the sedimentation not only of the grit or mineral matter, but also of much of the organic sewage matter. Such deposits are relatively large in quantity and exceedingly offensive in character. They are removed by manual labor, being shoveled, after draining, into buckets, or they may be dredged by various types of excavators capable of removing the grit from beneath the surface of the sewage, thus avoiding the emptying of the chambers. The more modern type of grit chamber, which may fairly be said to have originated in Germany, consists of one or more narrow channels through which the sewage is allowed to flow at velocities closely approximating 1 foot per second, at which the sand and gritty matter will deposit. These chambers are in turn shut off and drained, and the grit removed, ordinarily by manual labor. Under the best conditions this grit consists of a mixture of various sizes of sand comparatively little of which is finer than ordinary mortar sand. It contains relatively little organic matter, perhaps from 15 to 25 percent, and is less offensive than the grit removed from the larger and older type of chambers, where the velocity of flow is much lower. The quantity of grit removed will vary roughly between 10 and 40 parts per million.

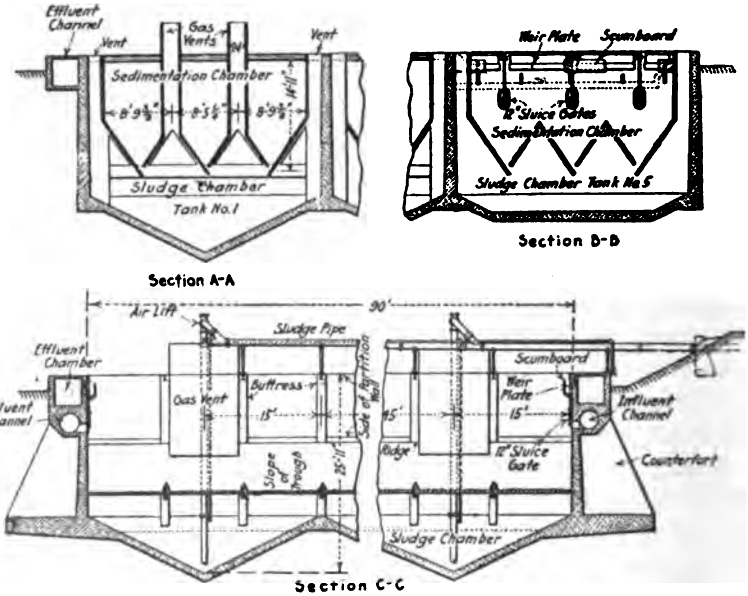
Plain Sedimentation: Plain sedimentation may be assumed to mean the process by which sewage is allowed to flow through horizontal or vertical tanks at velocities sufficiently low to permit substantially all of the suspended matter capable of settling in a reasonable length of time, to fall to the bottom of the tank, where it accumulates in the form of a mud, commonly called sludge.

It is necessary to remove this accumulation from time to time and it may be said in a general way that a plain sedimentation tank should be cleaned at intervals of from 3 to 6 weeks, depending upon the season of the year, or, more accurately, the temperature of the sewage. The object is to remove the sludge before decomposition becomes very active and causes portions of it to rise through the sewage, form a well-defined scum, or pass out of the tank in the effluent.

Septic Tank Treatment: The septic tank, a patented device, is similar to the plain sedimentation tank; in fact there is scarcely any difference between the two except in the method of operation. The septic tank is distinguished by being so operated as to ensure the absence of dissolved oxygen in the effluent and to permit of more or less complete decomposition of the solid substances in the sludge. This decomposition is accompanied by the production of large quantities of gas, due to biological action, and the gases are retained until the mass becomes sufficiently bouyant to rise rapidly to the surface, sometimes giving to the tank the appearance of ebullition. With these gases also rise large quantities of suspended matter, much of which is relatively coarse, especially if the sewage has not been screened, or has been screened only through coarse racks. This suspended matter holds entrained the gases, which in turn cause it to float at the surface of the tank. Repeated ebullitions of this kind cause the gradual accumulation of greater and greater quantities of this floating coarse suspended matter, which ultimately forms a thick scum attaining in some cases a thickness of two feet or more.

The septic tank, which at one time was looked upon with favor by some engineers, did not prove as satisfactory as was originally anticipated. The continuous evolution of gas from the sludge causes large quantities of suspended matter to be continually rising and falling through the liquid in the tank, which carries much of it out of the tank, thus defeating in part the object of the process. Furthermore, the changes due to anaerobic decomposition of organic matter appear to render the sewage rather more difficult to treat by processes of oxidation than fresh sewage which has not become impregnated with the gases and other products of decomposition. Septic sewage also frequently possesses an exceedingly offensive odor.

Two-story Tanks: A recognition of the defects in the septic process led to the construction of two types of two-story tanks: one, by Mr. William O. Travis of Hampton, England, and another by Dr. Karl Imhoff of Essen, Germany. The theory upon which these types of tank is based is that the sewage should be allowed to pass through the sedimentation chamber as rapidly as is compatible with the practically complete removal of the suspended matter capable of settling in a reasonable length of time and that the sludge should be permitted and encouraged to decompose in a chamber separate and distinct from that in which the sedimentation process is going on. The result of this plan is an effluent deprived of its suspended matter, and which has not come in contact with the decomposing sludge, and therefore does not contain the gases and other products of decomposition, nor the finely divided


Section A-A

Section B-B

Section C-C

Fig. 2. Sections of Imhoff Tank at Fitchburg, Mass.†

†From "American Sewerage Practice, Vol. 3, Disposal of Sewage."

suspended matter so prevalent in effluents from the septic tank. In fact where sewage is rather dilute and the temperature is moderate the effluent from such tanks frequently contains dissolved oxygen. Sections of the Imhoff tank are shown in Fig. 2.

Work Performed by Sedimentation: It may be assumed that of the 150 parts suspended solids capable of settling in two hours, perhaps 130 parts can be removed by efficient plain sedimentation. This is based on a tank efficiency of about 90 percent, computed upon the removal of settling solids. Upon this assumption the effluent will contain suspended colloidal matter which, together with the remaining settling solids, will amount to about 170 parts per million. In addition the effluent will contain about 500 parts of dissolved solids, of which about 50 parts has been classified as dissolved colloidal matter, 40 percent of which may be assumed to be organic.

Chemical Precipitation: If further improvement is desired a part of the remaining settling solids, suspended colloidal solids and dissolved colloidal substances may be removed. To accomplish this recourse was had many years ago to chemical precipitation. This consists of adding to the sewage certain chemicals like lime and sulphate of iron, which react upon each other in such a manner as to form a flocculent precipitate, which gathers in large flocculi which enclose and attract the finely divided suspended matter and some dissolved colloidal matter, and by their weight carry these substances to the bottom. In this way it is possible to greatly reduce the suspended solids and to effect some reduction in the so-called dissolved matter. This method has been subject to much objection on account of cost, the difficulty of disposing of the large quantity of sludge produced and of the partial removal, only, of the organic matter contained in the original sewage. Chemical precipitation is generally utilized by itself, although in some cases, particularly in the treatment of industrial wastes, it may be introduced as an adjunct to and following plain sedimentation and it may be used as a treatment preliminary to some method of filtration.

Sedimentation with Aeration: The most recent development in the art of removing suspended and colloidal substances from sewage is that known as the "activated sludge process". By this means it is possible to remove from ordinary municipal sewage a large part of the suspended and colloidal matter. As yet the installations are experimental, but are giving promising results. Suspended solids may be removed almost completely in the remarkably short time of four hours or even less. This process will be described in succeeding pages.

Work Performed by Sedimentation Aided by Methods of Removing Colloids: It has been pointed out that the effluent from efficient plain sedimentation will contain about 170 parts per million of settling and suspended colloidal matter, and about 50 parts of so-called dissolved colloidal matter, making a total of 220 parts per million.

Several ways of removing a portion or the whole of this matter have been suggested, among which may be mentioned sedimentation in tanks equipped with many vertical slats, or colloiders, chemical precipitation and the activated sludge treatment. The last method will accomplish more than is practicable under ordinary working conditions by either of the others, and in addition it will at the same time oxidize some of the dissolved substances; therefore, it cannot fairly be considered as simply a means of removing suspended and colloidal matter.

The most effective method devoted strictly to the removal of such substances, is chemical precipitation, by which much of the settling solids and colloidal matter can be removed. In addition to the 130 parts of settling solids which may be removed by plain sedimentation, about 160 parts of the settling solids and colloidal matter which escapes this process can be removed by chemical precipitation, leaving in the effluent from this process 60 parts per million, or less, of settling and colloidal matters. It is possible to go even further, but the cost of doing so has usually been prohibitive.

The effluent from sedimentation tanks may be discharged with propriety into some bodies of diluting water, but in many cases it is necessary to carry the process of purification further. Where chemical precipitation will provide a suitable effluent the choice between this method and some means of oxidation will depend upon their relative costs. In many cases, however, the effluent from chemical precipitation will not be adequately purified and it will be necessary to resort to an oxidation process. The failure of various tank treatments to remove fine suspended and colloidal matter and the necessity of oxidizing the organic matter of tank effluents before their discharge into natural waters, led to the development of processes for transforming this organic matter into stable substances, the demands of which for oxygen are not great enough to exhaust the supply or cause putrefaction.

CONTACT BED TREATMENT

Perhaps the most logical step ahead from tank treatment is the application of sewage to the contact bed. Such beds are built in water-tight compartments filled with broken stone or other similar medium to which bacteria become attached. The mass of stone is thus converted into an active bacterial medium over which the sewage gradually flows during the filling and discharging periods. and in contact with which it remains during the contact period. Such beds are operated in cycles of which the following is typical:

Time of filling	1.0 hour
Time of contact	0.75 "
Time of emptying	0.25 "
Time of resting	6.00 "
Time of cycle	8.00 "

While the sewage is in contact with the bacterial film or jelly surrounding the stones, its colloidal and dissolved substances are attracted to these films in which the bacteria are living and digesting the organic matter, thus brought to them. The changes which occur in the contact bed apparently consist of the initial removal of suspended and colloidal matters, its partial oxidation and the oxidation of matters in solution. By this process it is possible to so change the character of the sewage that even when undiluted it will remain stable or, in other words, will fail to putrefy, and may, therefore, be discharged into streams or bodies of water much smaller than those into which ordinary sedimentation tank effluent could properly be discharged. The effluent, however, is usually turbid, contains some suspended matter and is far from being fully oxidized. This process, which has met with some favor, both in this country and abroad, usually provides for two contacts, the

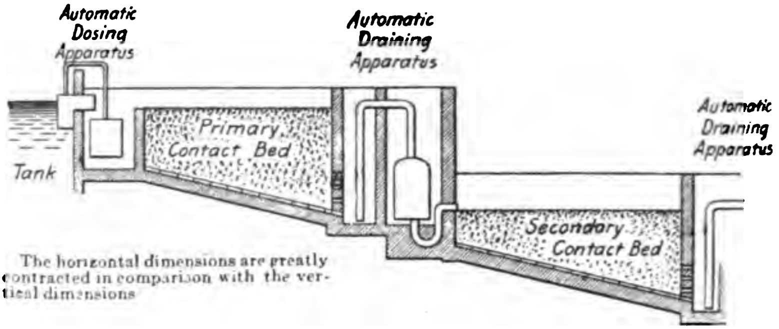

Automatic Dosing Apparatus
Automatic Draining Apparatus
Automatic Draining Apparatus
Tank
Primary Contact Bed
Secondary Contact Bed
The horizontal dimensions are greatly contracted in comparison with the vertical dimensions

Fig. 3. Typical Section Through Double Contact Beds.*

sewage being applied to a secondary bed after it has remained in the primary bed during the requisite period of contact. Figure 3 shows a typical double contact bed.

TRICKLING FILTER TREATMENT

The oxidizing power of all bacterial agencies depends upon an ample supply of atmospheric oxygen. This must be absorbed by the bacterial jelly of the contact bed, mainly during the rest period which is limited to a fraction of the operating cycle, rarely exceeding three-quarters of it. The quantitative efficiency of the contact bed is low also, because of its limited capacity for the storage of sewage in contact with the bacterial surfaces. These limitations have led to efforts to devise beds which would accomplish similar work without being subject to such restrictions. The most important derivative of the contact bed is the trickling filter.

Like the contact bed, this filter is composed of coarse grained particles, the most popular size at present perhaps being 1½ in. in longest dimension. The thickness of the beds varies from 5 to 10 ft., and their shape depends upon the method of distribution or local conditions of controlling importance. The stone is placed upon concrete or vitrified tile draining floors. The sewage is distributed as uniformly as may be over the surface of the bed, by revolving arm sprinklers, distributors moving backward and forward spreading the sewage as they go, or fixed pressure nozzles which spray the sewage, distributing it in a manner similar to that of the ordinary lawn fountain. Where the fixed pressure nozzle is used it is generally operated under a head diminishing throughout the discharge period from a maximum of about 7 ft. to the minimum, which varies from 1 to 2 ft. The dosing cycle may consist of a 5 minutes' dosing period and a 10 minutes' rest period.

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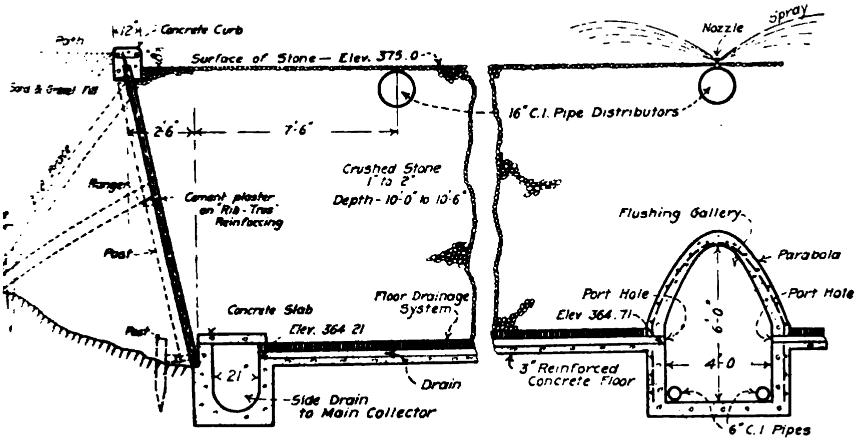
*From "American Sewerage Practice, Vol. 3, Disposal of Sewage."

This fluctuation in head may be obtained by a butterfly or undulating valve, rotated in the supply main, or by dosing tanks so designed as to provide the proper quantity of sewage at each head.

When sewage is first applied to a new trickling filter the suspended matter clings to the surface of the stones where it is temporarily retained, forming a suitable habitat for the bacteria present in the sewage. Thus a bacterial film, sometimes called bacterial jelly, is gradually built up, covering the surface of the stone of the entire bed. As the sewage trickles over this jelly-like substance, the finely-divided colloidal and some of the dissolved matter is retained upon and in it and apparently furnishes the food supply for the myriads of micro-organisms present. In this manner the sewage is deprived of its putrescible organic matter, which is gradually worked over by the organisms and ultimately given off to the passing sewage and carried away in the form of mineral or stable organic substances. It is of vital importance to provide the proper quantity of food supply and an ample opportunity for



Typical Section of Trickling Filter
Fitchburg, Mass. — Sewage Treatment Works.

Fig. 4. Typical Section of Trickling Filter.

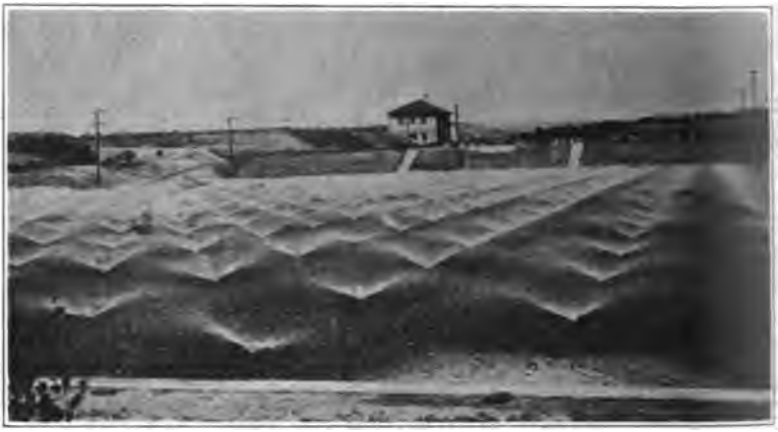


Fig. 5. Trickling Filter at Fitchburg, Mass.

the absorption of atmospheric oxygen. The operation of the filter is approximately continuous, and thus has a distinct advantage over the contact bed, which of necessity is both dosed and aerated periodically. A typical section of a trickling filter is shown in Fig. 4, and a general view in Fig. 5.

A very highly efficient trickling filter will carry the process of oxidation so far that the effluent will keep indefinitely, and if the contact material is relatively fine, the suspended matter of the sewage and the collodial matters withdrawn therefrom will be retained and a practically clear and sparkling effluent will be produced. Such a filter will cause a large reduction in the number of bacteria present in the original sewage. Trickling filters are ordinarily built of coarse stone, however, and contain interstices so large that the suspended matter which accumulates temporarily passes away after having been more or less completely worked over by the organisms. Such effluents are turbid and contain settling solids which are commonly removed in secondary sedimentation tanks. In fact, one of the primary objects in the design of trickling filters is to so construct them that the solids shall not accumulate indefinitely in the stone, but may wash out from time to time and thus avoid the necessity of taking out the stone to free it from the accumulation of such substances which otherwise might ultimately clog the filter. It is necessary, therefore, under ordi-

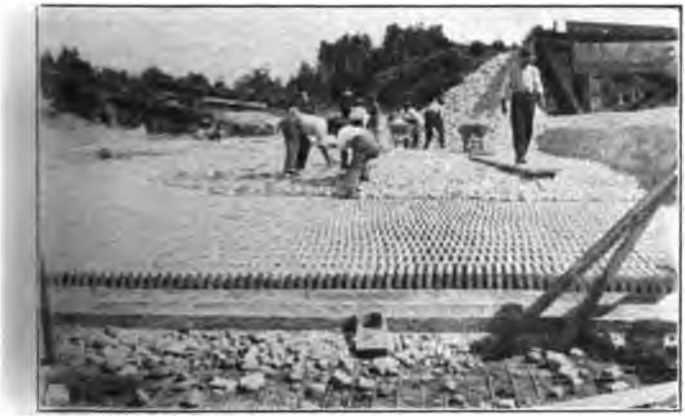


Fig. 6. Floor of Trickling Filter at Fitchburg, Mass.

nary conditions, to accept turbidity and much suspended matter, as characteristics of the effluent from this type of filter, and to provide for the removal of the settling solids before its discharge into the diluting waters.

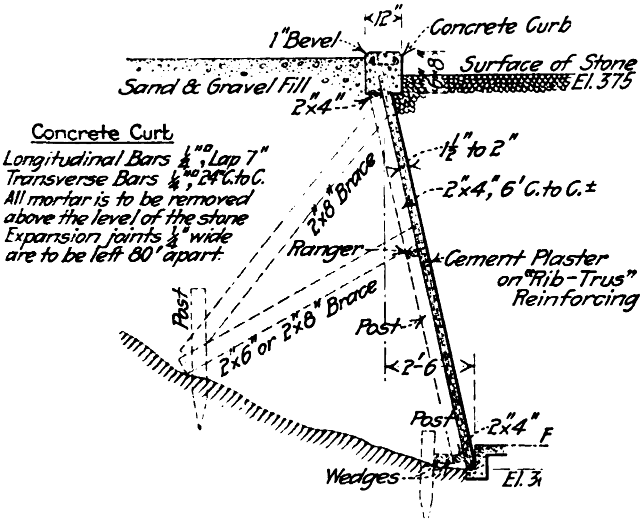


Fig. 7. Details of Wall for Trickling Filters.

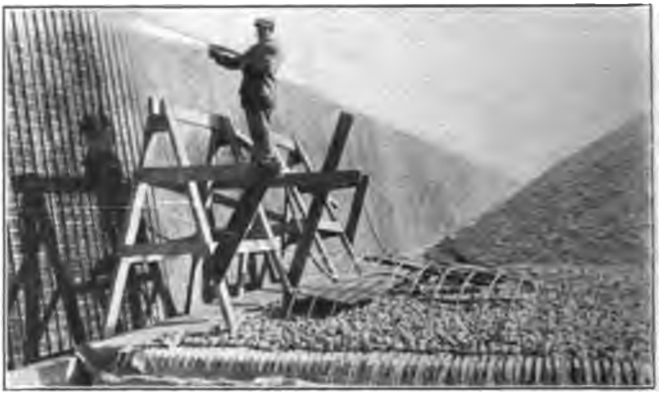


Fig. 8. Applying Cement Plaster to Wall of Trickling Filter.

The underdrainage system of the trickling filter is of great importance, since it is necessary to convey the effluent away freely, and also to provide ample means for washing out humus when the bed discharges its accumulation. Many types of filter floor have been used for this purpose. The cut, Fig. 6*, illustrates the one used at Fitchburg, Mass., which consists of a series of channels cast in the concrete floor, spanned with concrete beams or "bricks", the whole being covered with cobble stones before the filtering material was placed.

The walls of such a filter, if below the ground level, need be hardly more than diaphragms to prevent the material of the filters from mingling with the adjoining earth, and to keep the sewage or effluent from escaping into the soil. Such a diaphragm wall, built by plastering reinforcing steel with mortar by means of the cement gun, was employed at Fitchburg, and is shown in Figs. 7* and 8*.

SAND FILTERS

The intermittent sand filter is one of the oldest devices for the artificial treatment of sewage. It consists of a bed of sand from 3 to 5 ft. in depth, enclosed within embankments and usually provided with underdrains. It is necessary to use a free draining sand, if filters are to be capable of handling a reasonable quantity of sewage.

*Courtesy of Engineering News.

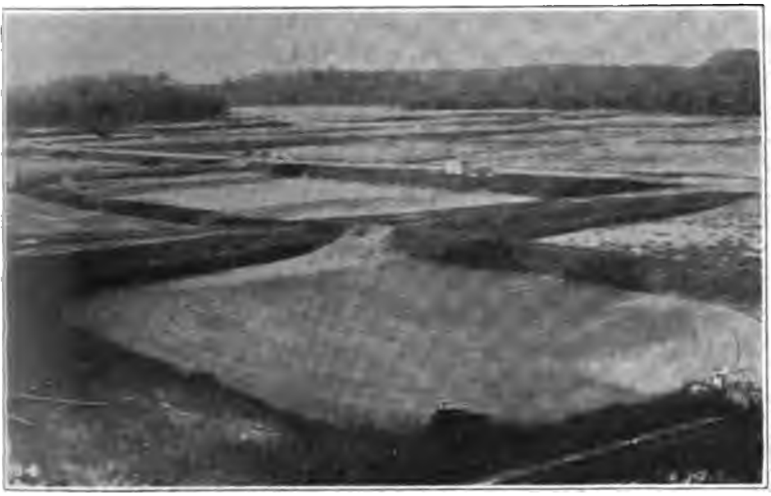


Fig. 9. Sand Filters at Marlborough, Mass.

As the name implies, these beds are operated intermittently. They are dosed by completely flooding the surface as quickly as possible, preventing excessive quantities of sewage from penetrating portions of the bed near the distributors, and thus aiding in uniform distribution. Dosing is best accomplished in the smaller plants by storing the sewage until the desired quantity has accumulated, when the dose is suddenly and quickly released by automatic apparatus.

The sewage percolates through the sand, where it comes in intimate contact with living organisms, as in the contact and trickling filters. In fact, the biological processes appear to be practically identical in these types of filters, although the oxidation is usually carried somewhat further in the sand beds. There is, however, one distinct difference between the sand filter and the trickling filter as ordinarily constructed and operated. The former, due to its fine particles and small interstices, retains the suspended solids mechanically, and is thus enabled to produce an effluent which is clear, sparkling and colorless. The trickling filter, as already explained, because of its large interstices, allows the suspended matter ultimately to pass through it, giving to the effluent a decidedly turbid appearance. A well-operated sand filter will carry the oxidation of the organic matter nearly to completion, converting it very largely into mineral substances. The bacterial reduction may also be far superior to that obtained by ordinary types of contact and trickling beds. Effluents in fact are obtained in which the bacteria are less than one percent of the number present in the original sewage, a result fully equal to that obtained by ordinary disinfection.

Obviously the retention of the suspended matter upon and in the sand causes a reduction in its capacity, and if this accumulation is permitted to increase indefinitely, the filter will become practically impervious to water. It is necessary, therefore, to provide for the periodic cleaning of the filters, which is accomplished by raking and scraping off the mat remaining upon the surface of the sand after the filter has become dry. Heavy mats necessitate frequent and expensive cleaning, which may be reduced, to some extent, by passing the sewage through sedimentation tanks before it is applied to the filters. It is usual, therefore, in such installations to combine with the sand filter, suitable sedimentation tanks for the removal of the coarser suspended matter.

The efficiency of sand filters, as well as of contact beds and trickling filters, is much lower during cold weather than in the summer. It is necessary to make ample provision for winter conditions, to avoid the freezing of the applied sewage in a solid layer adhering to the surface of the beds. This is accomplished by furrowing or by raking the surface material into piles, so that the ice sheet may be held up above the normal surface, thus providing a natural roof or cover, below which the sewage flows to the various parts of the bed, and which protects the sand from extreme cold and snow.

BROAD IRRIGATION

It is hardly necessary to discuss here the merits and demerits of broad irrigation, the oldest method of artificial oxidation of sewage upon land. This method has found little favor in this country.

It is capable, under favorable conditions, of producing a very highly purified effluent—fully equal to that of the sand filter.

DISINFECTION

The methods of sewage treatment thus far described, deal primarily with the prevention of objectionable deposits and offensive conditions. Disinfection deals with the destruction of organisms. Normal municipal sewage may be said to contain about one million bacteria per cubic centimeter, while they frequently run as high as 10 or 20 million per c. c. in old and strong sewages. Of these the great majority are probably harmless. Pathogenic organisms, however, may be present in sewage and the object of disinfection is to kill such organisms, or to so reduce their numbers that they may not be a menace to health.

For this purpose calcium hypochlorite, or bleaching powder, and liquid chlorine, have been used. The quantity required varies according to the quality of the sewage or effluent to be disinfected and the extent to which it is desired to reduce the number of bacteria. The quantity of available chlorine used, varies from 3 to 6 parts per million, which is equivalent to 25 to 50 lb. per million gallons of sewage. These quantities of chlorine are equivalent roughly to 75 to 150 lb. of bleaching powder per million gallons of sewage.

This treatment is not likely to produce a sterile effluent, but will reduce the number of bacteria growing at body temperature,—37 deg. cent.—from 75 to 90 percent and the coli from 90 to 95 percent. Such disinfection has been assumed to be sufficient when the effluent was discharged into tide water above oyster beds and an adequate protection of the public where the discharge was into large streams or bodies of water from which water supplies were taken, provided they were efficiently filtered and disinfected before use.

ACTIVATED SLUDGE TREATMENT

During the past two years the attention of sanitary engineers has been focussed upon a new method of sewage treatment known as the activated sludge process. This process appears to have been discovered accidentally by Messrs. Ardern and Lockett, who presented the results of their original experiments at Manchester, England, in the *Journal of the Society of Chemical Industry,* May

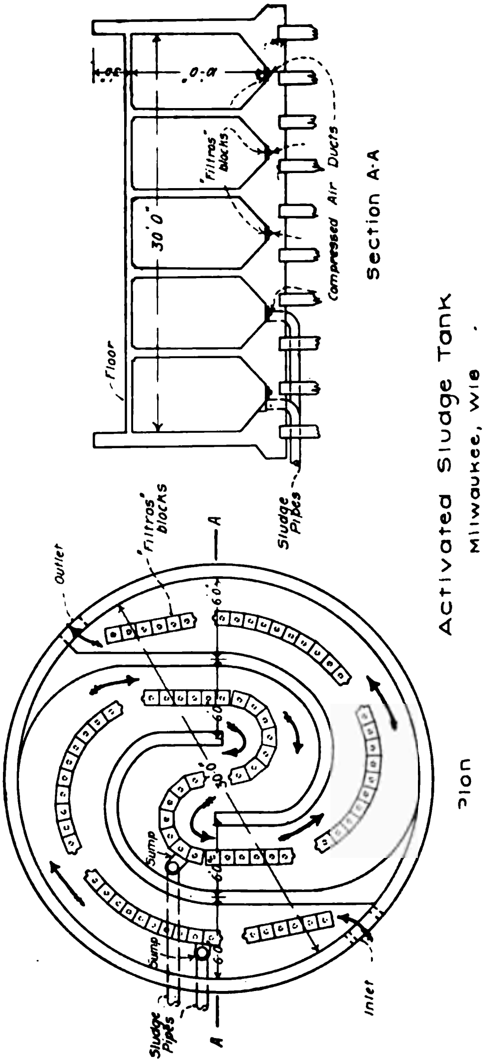


Fig. 10. Activated Sludge Tank.

30, 1914. They found that when sewage was kept for several hours in intimate contact with sewage sludge, by agitation with a current of air, the sludge assumed the form of a light flocculent precipitate, the suspended and colloidal substances were attracted to and absorbed by these flocculi and the dissolved matters were oxidized, the free ammonia being transformed into nitrates.

Milwaukee Experiments: Many experiments with this method of treatment have been made, the most notable perhaps being those of the Milwaukee Sewerage Commission, of which Mr. T. Chalkley Hatton is Chief Engineer, and Mr. William R. Copeland is Chief Chemist.

This process is still in an experimental stage, although at Milwaukee it was thought that sufficient progress had been made to warrant the construction of a 2-million gallon plant, which was completed in December and has been in operation two months. The plant consists of eight round aerating tanks 30 ft. in diameter and of sufficient depth to accommodate about 10 ft. of sewage, including 20 percent of sludge. Partitions are so arranged as to confine the sewage to channels 6 feet wide, through which it flows continuously, passing from tank to tank. From the aeration tanks it flows to a sedimentation tank, being admitted at a considerable depth below the surface, and flowing upward to skimming troughs into which it flows in a thin film at the surface of the tank. Two tanks of similar size are provided for the storage and re-aeration of the sludge collected in the sedimentation tank. The plant is also provided with the necessary air blowers and measuring devices. The equipment for handling, dewatering and drying the sludge, has not yet been fully determined upon.

Method of Operation: While the methods of treatment in different places, vary considerably, the concensus of opinion at the present time (1916) appears to be that operation by continuous flow through the aeration and sedimentation tanks is preferable to the fill and draw method which has been used in some of the smaller experiments. The process can be explained conveniently by describing the method of operation of the new Milwaukee plant as it is intended to be used when certain modifications have been made.

Sewage Aeration: Sewage flows continuously through the aerating tanks which are provided at the bottom with an air distribution system consisting of ducts above which are placed thin porous plates made by the General Filtration Company. These "filtros" plates are confined to a single row extending along the middle of the sewage channel. The air is admitted to the porous plates under a pressure slightly greater than that exerted by the overlying column of sewage. In this manner the sewage is constantly mixed with the sludge by the rising air, and at the same time the sludge and the liquid are afforded an opportunity to absorb oxygen from the air. Just before the sewage is admitted to the first aeration tank, it receives a dose of activated sludge, equivalent to 20 percent of its volume. The method of preparing this sludge will be described later.

The period of aeration is intended to be about 4 hours, which obviously corresponds to the length of time required for the sewage to flow through the eight aeration tanks. The quantity of air required for aeration of the sewage appears to be about 1.75 cu. ft. of free air per gallon of sewage treated.

Sedimentation: As it is important to maintain the sludge in intimate contact with all portions of the sewage in the aerating tanks, it is necessary to provide for sedimentation immediately after the sewage leaves them. The flocculent precipitate, however, settles quickly and a clear effluent can be obtained from suitable sedimentation tanks. It is expected at Milwaukee to reduce the quantity of suspended matter in the sewage to less than 20 parts per million, as the effluent leaves the sedimentation tank. The suspended matter gradually falls to the bottom where it accumulates as a thin sludge.

Sludge Handling: From the sedimentation tank in which the sludge naturally contains 98 or 99 percent water, the sludge flows to a deep concentration well where it is hoped to reduce the water content to 96 percent or less. From this well the sludge may be pumped into the incoming sewage or, when necessary, to the sludge reservoirs where it is continuously aerated to reactivate it before pumping it to the raw sewage.

There are as yet very few data to indicate the quantity of sludge likely to be produced by the activated sludge treatment of sewages in general. The Milwaukee experiments indicate that the quantity will range from 3000 to 6000 gal. per million gallons of sewage treated. This sewage is relatively strong, its volume being equivalent recently to about 80 gallons per capita per day. It contains considerable industrial wastes and may produce an abnormal quantity of sludge.

Analyses of this sludge indicate that when dry it contains sufficient fertilizing ingredients to make its utilization commercially attractive. There are, however, serious difficulties to be overcome in dewatering and drying the sludge. Very little progress has been made upon this phase of the problem.

Theory of Action: The most noticeable effect of this treatment upon the sewage, is the formation of the precipitate called "activated sludge". It is light brown in color, apparently very light in weight, and readily forms loose aggregations called "flocculi", resembling precipitated hydrate of iron. These flocculi are found to contain vast numbers of bacteria, which appear to be absolutely essential to the success of the process. It is conceivable that they exude certain substances which give to these flocculi their peculiar absorptive and attractive functions, and which enable them, while passing through the sewage, to gather to themselves the colloidal matter and bacteria, and to absorb certain of the dissolved substances.

The action of this sludge appears to be very similar to that of the bacterial jelly surrounding the stones of the trickling filter. The chemical changes which go on in the sewage, in both processes, appear to be practically identical. The efficiency, however, of the activated sludge flocculi, in holding the colloidal matter, appears to be greater than that of the bacterial jelly of the trickling filter, for the effluent from the aeration tanks, after proper sedimentation, is very clear and sparkling, while the effluent from ordinary trickling filters, even when in relatively good condition, is almost always turbid, even after the settling solids have been removed from it by sedimentation. The two processes although very similar in theory of action, are carried on under different physical conditions. In the case of the trickling filter, the sewage is the moving medium, passing slowly over the absorbing jelly, by which its finely divided particles and some of the dissolved matter are absorbed, and subjected to bacterial decomposition and oxidation. In the aerating tanks, on the other hand, the bacterial jelly is the moving medium, which, in contact with the sewage, attracts and absorbs the finely divided and some of the dissolved substances, and within its confines subjects them to bacterial decomposition and oxidation.

Character of Resulting Effluent: The well settled effluent from the aerating tanks as observed by the writer at Milwaukee is clear, sparkling and colorless. It contains ordinarily less than 10 percent as many bacteria as were present in the original sewage; it is relatively stable, keeping under exacting laboratory conditions for from three to five days, even in the winter when there is practically no nitrification, due apparently to low temperature of the sewage. In warmer weather there should be no difficulty in producing a stable effluent and even a highly nitrified effluent.

Application to Trade Wastes: This method appears to be adapted to the treatment of certain trade wastes. Experiments being made by the writer upon tannery wastes, give promising results, while those upon paper mill wastes are not encouraging, probably because these wastes are not as susceptible to vigorous bacterial action.

Cost: It is too early to base estimate of cost of this process upon actual operating data. The expense will apparently be divided into two parts, that of the purification process and that of sludge disposal. Air alone, at the rate of 1¾ cu. ft. of free air per gallon of sewage treated, will cost about $14 per million gallons of sewage, if power costs 2c per k. w. h. Few small cities can hope to purchase power at a much lower cost, and other methods of treatment are likely to prove more economical unless a profit can be realized from the sludge.

Analyses of activated sludge from different experimental plants vary widely. Some indicate the possibility of a return from sale of commercially dry sludge, sufficient to warrant the payment of a substantial sum for dewatering and drying, but what these processes will cost is now problematical.

COMPARISON OF RESULTS OF METHODS OF SEWAGE TREATMENT

Sedimentation with or without screening, is capable of removing much of the suspended matter capable of settling in a short time. Referring again to the hypothetical sewage, by way of illustration, it may be assumed that this process will effect a removal of about 130 parts per million of suspended solids. This leaves 170 parts of suspended solids and 500 parts of dissolved solids,—an highly putrescible effluent which is decidedly dirty in appearance. Such an effluent, however, may be turned into some streams and bodies of water without fear of causing serious deposits, and the quantities of diluting water may be such as to fully warrant such a course.

If, however, a better effluent be required, resort may be had to chemical precipitation, by which it is possible to remove colloidal and suspended matters more completely than by sedimentation, and to the extent of perhaps 290 parts per million, leaving 510 parts of suspended colloidal and crystalloidal matter in the effluent of the hypothetical sewage. A large part of this consists of soluble matter. Even this reduction is not sufficient to render the effluent non-putrescible, and it might be added that in most cases where this method has been employed the operating costs have been so curtailed that the results obtained have hardly been comparable with those of which the process is capable.

The quantity of suspended and colloidal substances removed by screens, grit chambers, sedimentation and chemical precipitation may be tabulated as follows:

Coarse Screens	5 to 10	parts	per	million
Fine Screens	20 to 70	“	“	“
Grit Chambers	10 to 40	“	“	“
Plain Sedimentation	130	“	“	“
Chemical Precipitation	290	“	“	“
Activated Sludge, more than	290	“	“	“

All of these methods, therefore, leave in the sewage some suspended and colloidal matter and practically all of the crystalloidal substances. Where further purification is required, methods of oxidation are employed.

The results obtained by bacterial oxidation in sand or stone beds, have varied greatly. The best results can be obtained undoubtedly by the use of sand filters, with which a clear, sparkling non-putrescible effluent can be produced without difficulty. Such an effluent is as good as can be obtained by any of the available processes and may contain no more bacteria than a well disinfected settled sewage.

The activated sludge method produces a clear, sparkling, well-oxidized effluent. Its bacterial efficiency apparently approaches that of the sand filter, as does its power of oxidation and removal of organic matter.

To any one of these methods it is practicable to add disinfection with chlorine, which will reduce the number of organisms to such an extent that the discharge of the effluent into tidal waters or into large bodies of water from which water supplies are taken and properly filtered and disinfected, should not endanger health.

By available methods it is practicable to produce an effluent of almost any required degree of purification. Local conditions in one place may favor the adoption of one method, while those of some other city may warrant an entirely different process. In general, where large bodies of water are available for dilution it is unnecessary to adopt artificial means of oxidizing the organic matter. While natural resources for the oxidation of sewage should be utilized as fully as is compatible with the general welfare, they should not be abused by the discharge of overtaxing loads of organic matter into streams and waters, by which their value of natural resources is destroyed wholly or in part.

The problem before the engineer today is not so much how it is possible to purify sewage as it is to determine to what extent the sewage should be purified to meet the existing conditions and by what process can this be most economically accomplished.

DISCUSSION

Mr. N. S. Sprague:* I did not come prepared to discuss the paper which has been so ably presented by Mr. Eddy. Nevertheless, I am deeply interested in the subject of sewage disposal and it occurred to me as the paper was being read that there was possibly one point which could be emphasized and that is this—that the control of the streams throughout the different states is vested largely in the Boards of Health, and in many instances there is no well defined policy in many of the states as to what degree of sewage purification should be required.

In Pennsylvania, for instance, there are some rivers that are

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used almost exclusively for water supply, and there are others where the condition of the water is such as to preclude the possibility of such use without extensive filtration and purification works. It is questions like these that should be given very serious consideration by state authorities in determining the degree of purification which should be required. It rests in the last analysis with the state authorities and the state boards of health should have a well defined policy with regard to stream and river pollution, based upon the present and future use of these waters for transportation, water supply and other purposes. With such a policy established and knowing the character of the water in the different streams and rivers, it then becomes a question of how much, if any, treatment of the sewage is necessary to preserve the purity of the waters and prevent nuisance.

The question of the degree of sewage purification, therefore, where the sewage is to be discharged into a water course is a very broad one and requires extensive knowledge of the future use of the waters into which it is discharged. The city or town designing sewerage works cannot afford to pay the cost of such extended investigations and therefore this duty (the responsibility of deciding to what extent the sewage shall be purified) was delegated to the state authorities. The City of Pittsburgh will undoubtedly be confronted with the question of purification of sewage one of these days, and the question of the degree of purification is a serious matter. The purity of those waters which are used for water supply purposes will have to be maintained at such a standard as to make possible its filtration for water supply purposes at a reasonable cost, and will therefore require sewerage works which will produce an effluent to meet this standard. Where the question of water supply is not involved, the treatment of the sewage discharged into the rivers or streams should be determined upon the question of local or general nuisance and the ability of such waters to assimilate the sewage.

Mr. Paul Didier:* Like Mr. Sprague, I did not come prepared to discuss this paper. However, I understood Mr. Eddy to say that they could never make the sludge in a commercial way to sell it.

By taking exception to the statement that the sludge is not now of any commercial value, I have reference to the various sewage-farm plants now in operation in Europe, and principally the one operated by the city of Paris, where there are four distinct sewage-farms with a total of about 14 000 or 15 000 acres of land on which is distributed daily about two hundred millions of U. S gallons of sewage, and, as I understand it, the sale of the sludge helps to absorb a large portion of the operating expense.

Sludge, of course, can only be put on a commercial basis through irrigation processes as is generally used on what is known as *sewage-farms* for which porous or sandy soil lands are required, and a very high degree of purification can be obtained by this method without any detriment to the richness of the sludge as a market product for fertilization purposes.

Quite a number of sewage-farms are still in existence and operation notwithstanding the various mechanical and chemical treatments now in vogue where the sludge has no longer any commercial value as fertilizer, and is considered only a burden. Sewage-farming is a combination of mechanical, biological and chemical action. The soil acts as a strainer and at the same time affords a home for innumerable bacteria, which seize upon the organic matter in the sewage, transforming it into plant food and gases, and at the same time changing its chemical composition. The process is essentially one of oxidation and nitrification. The sale price of the sludge when seasoned, or in other words just ripe and ready to assist the farmer, truck-gardener, florist, etc., in their crops, is entirely dependent on its chemical composition. and is auctioned off at its fertilizing value.

In sewage-farms where there is no natural porous nor sandy soil to be secured, artificial drains may be and are placed in subsoil to carry off all percolating matters through a system of tile and hasten the drying of the sludge.

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MR. THOMAS FLEMING, JR.:* The writer regrets very much that he cannot be present to take part in the discussion of Mr. Eddy's paper, which, judging from the title and outline submitted, promises to be most interesting and valuable.

There is one feature of this subject which the writer wishes to discuss briefly, and that is, "The extent to which sewage must be purified."

Many of our sanitary engineers seem to aim at idealism in sewage disposal and insist on installing elaborate disposal works with the aim of giving a high efficiency, regardless of the condition of the stream into which the effluent is to be discharged. The result is that in many instances the cost is prohibitive and nothing is done, or, on the other hand where the funds can be raised, the tax-payers are loaded down with a high annual charge for interest and depreciation on a big investment, in addition to high operating charges.

As a typical example, the writer was recently called into consultation by a municipality in Western Pennsylvania where it was vitally important to extend the sewerage system, and yet under the decree of the State Department of Health, no extension could be undertaken until arrangements were made to treat the sewage. It was found that the stream into which the sewage discharged was badly polluted by factory wastes, but in the face of these conditions, plans for an elaborate disposal works had been prepared by a well known sanitary engineer, and on account of the high initial cost, the bond issue for this work had been overwhelmingly defeated at the public election.

A partial disposal works consisting of the removal of the suspended matter by sedimentation in a double-story tank, and the disinfection of the effluent with chlorine, was recommended by the writer as all that was necessary under the conditions. This was approved by the State Board of Health and subsequently ratified by the people. This plant is now under construction and the cost will be less than one-fourth of the complete and elaborate plant originally proposed.

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Similar conditions occur frequently, especially in the mining districts of Pennsylvania, where the streams are unfit for use for drinking purposes due to the existence of mine waste and drainage. Out of the twenty odd sewage disposal propositions with which the writer has had to deal, only seven have required a highly purified effluent.

There is also the possibility of installing a temporary plant for partial disposal which can be abandoned when complete purification is desired, and at the same time effect a considerable saving from an economic standpoint, without impairing the efficiency.

The writer now has two cases where fine mechanical screens with disinfection of effluent by liquid chlorine can be installed to advantage and later abandoned when complete disposal works are necessary.

In both these cases, it would require several miles of outfall sewer laid under difficult conditions to a suitable disposal plant site below the towns, and also the continuous operation of a pumping station, if a portion of the permanent works were installed, but by locating a screening plant in the towns, this expenditure is saved. In both cases the operating cost of screens, due to disposal of sludge, is materially reduced by the existence of municipal garbage crematories, and as it will probably be ten years before a more complete purification is required, these screens will last their lifetime.

The ultimate complete purification of the sewage must, however, be kept in mind in designing a plant for partial disposal under existing conditions, for with the existing laws relating to the purity of streams and the splendid work of the State Boards of Health of our leading states in enforcing them, the time is bound to come in many instances when complete purification will be desired. It is well, therefore, in all cases to make provision for the addition of filters or other units for secondary treatment so as to ultimately have complete purification.

PROF. W. E. MOTT:* I have no discussion prepared but would like to ask if an attempt has ever been made to use any-

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thing in the nature of the Cottrell process for eliminating colloidal matter.

The slide showing the "Colloider" suggested the flow of sewage in thin streams as the rods must rather minutely subdivide the flow. Would it be possible in this case to apply anything like the Cottrell process which is used for the removal of the fine particles of matter from the air?

THE AUTHOR: I do not know enough of the Cottrell process to answer the question. The nearest approach to it that I know is the slate beds. In that system the stream is cut up into small films. No electric current is used, however. The idea of the slate bed is very similar to the colloider designed by Dr. Wm. Owen Travis. These slates in the original bed which was built at Sutton, England, were about one inch thick, and the tank filled with them was simply filled with the sewage and the laws of attraction and absorption applied in that way. Experimental work has been done by the Massachusetts State Board of Health along that line, but so far as I know there has been nothing on a practical scale in this country.

PROF. GEORGE W. CASE:* Mr. Eddy has handled his subject so thoroughly that there is nothing additional which I may offer unless it is to call attention to a local condition. In Pittsburgh, we have followed the time honored custom of dumping our sewage into adjacent rivers. We have hoped that no damage would be done and at the present time probably none is being done during the largest part of the year. There is a time, though, during the late summer and early fall when the discharge of the rivers become small, when this practice may not be free from danger. We have come to the time now, and in fact, have been there for some time, when it is unsafe to use any river water for domestic purposes without first treating it. Our problem then is,—what dilution should our sewage receive to make the Ohio River free from nuisance?

The flow of the Ohio River at Pittsburgh at low water stage is about 1200 second feet according to the report of the Flood Commission. This quantity gives a dilution of a little more than two cubic feet per second per 1000 population for the City of Pittsburgh; a dilution generally considered about one-half the proper amount. With the regulating dams up the Allegheny and the Monongahela Rivers, this minimum can be raised to about 8 cu. ft. per sec. according to the above report, an amount certainly sufficient to free the City of Pittsburgh from criticism for practicing this method of disposal.

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If the money needed for sewage treatment plants under the present conditions were spent for regulating dams, the problems of improper sewage disposal, flood damage and poor river transportation facilities would be fairly solved.

A question I would like to ask Mr. Eddy is this: Can sludge from sewage treatment plants be economically treated to give it fertilizing value? We hear a great deal about using sludge for fertilizer. I realize that it may be used to add humus to the soil and I believe that it has in some cases paid well for the labor needed to get it on the land for this purpose, but it seems to me a mistake for people to be given the understanding that the sludge from their plant will have value for fertilizing purposes.

A complete fertilizer contains potash, phosphorus and nitrogen. None of these agents are present in sludge in large enough amounts to speak of, so if they can not be added in some way economically and let the sludge simply act as a humus forming agent, the value of sludge as a fertilizer should be considered nil.

I know of one place where a city is getting its sludge taken from the beds and hauled away free of charge and I believe, under like conditions, other cities might properly profit. At this place a farmer has been doing this work for sometime under the supposition that through scheming with the plant operator, he is cheating the city out of something valuable. He is simply buying his gold brick in a different form.

Mr. Harry J. Lewis:* Under present conditions of sewage disposal and purification, it would seem to be very hard to recover a valuable fertilizer at a cost which will permit its use by the farmer. As long as the principle of maximum dilution is followed the potash and ammonia with much of the phosphates pass into solution and can hardly be recovered by any process short of evaporation. This is, if course, too expensive.

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With over half of our population in cities, consuming the best products of the soil it would seem necessary that they should give back as much as possible of their waste to conserve the producing power of the soil. Any other course means an increasing cost of living in the cities which must limit their growth and ultimately turn them in the other direction. This may be the real story of the buried cities of the older civilization. Would it not be well to give some consideration to this recovery of valuable constituents of sewage before going too far in the direction of purification methods which make recovery economically impossible?

MR. W. C. HAWLEY:† I did not come to the meeting with any intention of discussing this paper. Sewerage is something I have had little to do with for several years. It seems to me, however, that the difficult question for the engineer to determine is the extent to which purification of sewage should be carried and the reasonable expenditure that a municipality should make for that purpose. As against sewage purification, it may be said that if the water taken for municipal supplies is to be filtered, why go to any considerable expense to purify the sewage before dumping it into the stream. The benefit seems to be only to those who live down stream. This is a very narrow and selfish view. "The philosophy of Americans should be the work for each others interests."

The answer to such an argument is obvious. It is just as much murder to dump raw sewage into a stream and cause the death of persons using the water from the streams below as it would be to throw prussic acid into the stream with the same results. Our State "Purity of Water Act" (Act of 1905) recognizes this fact and gives great powers to the State authorities to remedy existing conditions and to prevent future pollution of streams by sewage. Our State Department of Health has had great difficulty in enforcing the law, because the vast majority of the people living on the water sheds were not educated to the necessity of caring for the water supplies, and while demanding of their local government officials improved paving, ornamental lighting, expensive municipal buildings, statuary or memorial fountains, in fact anything other than the sanitary disposal of sewage, have failed to realize that not only would their negligence result in suffering and death to their neighbors down stream but that their own citizens while visiting the communities affected by their own negligence might contract disease and bring it back to their own homes.

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There is another reason why our streams should be kept pure, and it was called to my attention particularly last summer while canoeing on the Allegheny River in the vicinity of Oakmont and Verona. I am not familiar with conditions on the Ohio River below Pittsburgh, but they must be even worse than those of the Allegheny River. That part of the river is the playground during the summer for thousands of people from Pittsburgh and the boroughs to the East, and every year there is an increase in the amount of typhoid in the months of August, September and October, part of which at least can be directly traced to people boating, swimming and camping on the shores of the Allegheny. Many of these people cannot afford to go away for a vacation but can go to the river for an afternoon or a day and many camp on the river during the season, going back and forth to their work. That the health and lives of these people should be endangered by the impurity of the river water is a serious condition and one which should be remedied and can be remedied, if the communities up stream can be compelled to properly purify their sewage.

In considering the extent to which sewage purification must be carried, the engineer must study not only present conditions, but the future with its increase of population and the difficulties which this increase will add to the problem.

MR. JOHN M. RICE:* Mr. Eddy has shown a chart for purposes of discussion, giving the composition of sewage as 800 parts of organic matter in a million, but we must always remember that the actual amount of organic matter to be taken care of in any purification plant will vary directly with the population and to less degree with the industrial uses, but that the plant must be designed for treating a greatly fluctuating amount of water depending on the water consumption of the city, and the type of sewage system.

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Thus a city like Pittsburgh which has a water consumption of something like 210 gallons per capita will require a much larger plant investment than some of the European cities where the use per capita is only from 20 to 40 gallons.

We have recently designed and constructed a plant consisting of an Imhoff tank and contact filter which treats water from a separate sewage system, serving part of the town and the dry sewage collected in cans from the remaining part, and this unusual condition required a departure from the proportions usually found.

There is another condition we have to face in those cities where the combined system of sewage is used, where it is frequently impracticable on account of expense to put in an entirely new sanitary system which will take care of house sewage separately, although some of the authorities have insisted upon that. In such cases it is the practice to build a plant large enough to take care of what might be called the household sewage plus part of the dry weather flow and a small part of the storm runoff, and to permit the remaining storm water flow to be discharged without treatment.

MR. CHARLES M. REPPERT:* The speaker of the evening has clearly and ably described the methods by which varying degrees of purification of sewage may be attained and it may be of interest to point out one or two factors which must be considered in fixing the degree of purification required.

Where the existing system of drainage is on the combined plan and where plans for treatment are being considered, either the plan of sewerage must be changed to the separate plan, or dry-weather intercepters must be constructed or diversions installed.

The installation of a separate system under such conditions would be very costly, perhaps prohibitive, and generally unwarranted except in the most extreme cases. Studies made in Pittsburgh a few years ago indicated that the cost of installing the separate system including the changing and altering of house plumbing, new house laterals and street repaving, would average about $700 per acre for the entire city; this cost being exclusive of trunk sewers.

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If the use of the combined sewers is to be continued, the degree of purification should be materially less than would otherwise be the case. It is a well recognized fact that the storm flow, even the yield of moderate rains, is so greatly in excess of the dry-weather flow of sewage that its treatment is entirely out of the question by any known method. This being the case, storm water, more or less polluted with sewer flushing and the washing of streets and ground surface, will enter the water courses and at such times endanger the use of the stream as a source of water supply, unless filtered. Provision may be made to treat a discharge somewhat in excess of the dry-weather flow, and if this is done the frequency of the discharge of untreated sewage into the stream will be reduced. It is sometimes stated that such excess capacity will enable the treatment (at perhaps a higher rate) of the entire discharge during the early stages of the run-off and thus make possible the treatment of the first wash of the streets and sewers, but, except where the area under consideration is relatively small, this will very rarely be accomplished to any appreciable extent, owing to the time necessary for the concentration of the flow, as it will generally happen that the first washings from the greater part of the area would not reach a treatment plant until its capacity had been exceeded by the storm water yield from the adjacent areas.

Some local studies of drainage conditions in areas ranging from 2000 to 4000 acres have indicated that provisions of four times the ordinary dry-weather flow would suffice only for rain fall rates of between 0.15 and 0.25 inches per hour. Under these conditions, the more or less frequent discharge of untreated sewage into the stream imposes limiting conditions on the degree to which treatment should be carried.

Where the sewage formerly discharged into a stream at a number of more or less separated points is concentrated for treatment at a plant, the effect of the effluent, if treatment is not carried to a sufficiently high degree, upon the stream must be considered. The load upon the stream where the less intensive methods are resorted to, such as fine screening or sedimentation, will be appreciably greater than if an effluent of the same quality was delivered to the stream at a number of points.

Locally, the effects of a discharge from a large population are minimized by the fact that sewage is received by the rivers from over 100 outlets, scattered along miles of river front. If the sewage is to be concentrated at a single plant, then the treatment must be carried much farther than would otherwise be the case. As an alternative, where possible, several smaller plants could be built. The construction of well designed submerged outlets so as to secure a thorough diffusion of the discharge well in the body of the stream will do much to prevent local nuisance along the shores and enable the stream more readily to take up its load.

MR. J. E. RUSH :* I, too, will have to plead that I am not prepared to discuss Mr. Eddy's paper, but it has been most gratifying to me to be present and to hear the subject of "Sewage Disposal" so ably handled. It is particularly pleasing to one whose interests are chiefly biological to hear such a prominent engineer as Mr. Eddy emphasize the great importance of the biological factors concerned in sewage disposal. We have been too ready in the past to consider this whole phenomena as one which has a mechanical or chemical basis, when, as a matter of fact the underlying principle determining the success or failure of a given system is the presence or absence of a certain bacterial flora which will produce the results desired. The different mechanical contrivances are employed purely and simply for the fostering of the growths of the desired organisms and are only successful in so far as they fulfill this mission.

I believe that most of our energy used in the study of this problem should be devoted to the biological factors concerned. If the problem of decency is neglected, the only remaining reason for instituting sewage disposal plants is because we desire a safe and sure method of disposing of the etiological factors in the spread of many diseases and this of course means properly disposing of the waste materials from the body which may contain pathogenic bacteria. The whole problem is intimately concerned with the biological factors involved. First, we wish to rid ourselves in no doubtful manner of those bacteria which may cause disease and secondly, we wish to produce certain results which are entirely dependent upon the presence of certain bacteria during the period that the sewage is in the container used, just before the discharge of the effluent. The character of the effluent depends upon the bacterial flora with which it has come in contact.

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Mr. Lewis' remarks on the depletion of soils so far as their nitrogen content is concerned also interested me. Here again we are aided by the science of bacteriology and in quite the same way as we are helped in the problem of sewage disposal. The most important agency concerned in the returning of nitrogen to the soil (that part which has been lost through the removal of crops) is bacteria and it is only necessary to provide a proper environment for their activities in order that this element may be replaced.

MR. L. P. BLUM :* I desire to emphasize the point that Mr. Eddy made that purification is necessary before the water of a stream can be used for domestic purposes. There seems to be a popular idea that somehow or other, sewage can be economically transformed into drinking water, and any engineer who takes his part in combating that proposition is rendering a public service.

Referring to the subject of the combined system of sewage, I call attention to the last report of the Department of Public Works in the City of Philadelphia, where an ingenious scheme is worked out in detail for the use of a combined system of sewers for purifying, to a certain extent, the sewage of a large city. I would like to ask a couple of questions of Mr. Eddy.

How would these colloiders of which he speaks be cleaned?

Is a garbage incinerator a help in the disposal of sewage sludge and if so, how can it be thus used?

MR. HARRISON P. EDDY :* In answer to one of the last two questions I may point out that the slat colloiders are not intended to be cleaned artificially. The theory is that the colloids will attach themselves to the staves and form a gradually increasing film about them. When the film becomes sufficiently thick and heavy it will fall off the staves and thus automatically clean them.

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*Of Blum, Weldin & Co., Consulting Engineers, Pittsburgh.
*Author's closure.

How it works in practice I do not know. The plant at Norwich, England, had only just been put in use when I saw it and I have not heard what results are obtained.

As to the other question, so far as I know the garbage incinerator has not been used much for incinerating sludge. Small incinerators—merely boiler furnaces—are used for burning screenings. In Cleveland they have installed a little garbage crematory for the express purpose of incinerating screenings. In England sewage sludge has been mixed with ash refuse and garbage and burned.

Now as to the value of the sludge, nobody denies that there is much of value in sewage. The chief element is the nitrogen. There are also some potash and phosphorus compounds. As with gold in sea water, there is no question that the value is there but, as Mr. Lewis says, "to tie a string to it and pull it out is another thing." The potash and much of the nitrogen and phosphorus is in solution and when the effluent is discharged these substances are gone. The new method, called the activated sludge process, which utilizes some of the old principles in a new way, appears to be able to take out the fine colloidal substances which were not removed by the older methods of sedimentation. Those substances are relatively high in nitrogen and the sludge resulting from the use of this process appears to contain about twice as much nitrogen as ordinary sludge. You may ask why that does not happen in chemical precipitation. It does, but there is precipitated also a large quantity of hydrate of iron and alumina, sulphate and carbonate of lime and other compounds which so dilute it that there is not enough nitrogen to give much value to the sludge.

I do not question for a moment that sludge has been sold. I presume it is being sold today at Glasgow. At Worcester, Mass., the farmers used to haul the sludge, containing 75 percent of water, four or five miles. Some of these farmers are good practical market gardeners and they came year after year, and I presume they are still hauling three or four thousand two-horse loads a year. While they were hauling 3000 loads the plant was producing 6000 or 7000 loads and the demand was not sufficient to take the whole product.

With the combined system of sewers the street detritus dilutes the fertilizing ingredients of the sludge with useless mineral and organic matter.

The great difficulty in utilizing sludge from the activated sludge process is going to be in dewatering and drying it. Apparently that must be done mechanically and it will probably be done in three steps. First, the liquid sludge will be concentrated in deep wells, thus decreasing the water from 99 or 98 percent to 96 or 95 percent. This must be done quickly, for the liquid sludge will soon putrefy. The second step will be to press that concentrated sludge in some machine similar to a filter press or a centrifuge, thus reducing the water content to 75 or 60 percent. Then the sludge which is in suitable condition for shoveling may be put through a revolving dryer and have its moisture reduced to 10 percent. After this it may have to be decreased. It will then be ready to grind, bag and market. Some may doubt the wisdom of an attempt to carry out a process of this kind by an ordinary American municipality.

Mr. Hawley spoke about the prevention of bacterial contamination of rivers on account of their use as sources of water supply and for boating, bathing and other pleasure purposes. Two distinct problems are thus presented. It is absolutely necessary to provide a safe water supply, whatever may be the expense incurred. In most cases, however, it is neither necessary nor economical to place upon the sewage treatment plant the entire burden of preventing bacterial contamination due to the discharge of municipal sewage. In spite of the fact that the sewage of Pittsburgh and many other communities is discharged into the Ohio River, Cincinnati, by means of its water purification plant, aided by the processes of Nature going on in the river, is able to render the river water safe for domestic consumption. As a result of this water treatment, the typhoid death rate in Cincinnati has been reduced from an average of 54 per 100 000, prior to the introduction of water purification in 1907, to 11 per 100 000 for the five year period 1908-1912, the latter rate being in no way indicative of an unsafe water supply. In this case, if no sewage whatever were discharged into the river above the city, it would still be necessary to treat the water to render it suitable for domestic consumption. It is therefore the part of economy to postpone the expense of sewage treatment until such time as the load upon the water purification plant is so great as to endanger the safety of the water.

While it must be conceded that absence of contamination by pathogenic bacteria is necessary to absolute safety in the enjoyment of bathing and boating upon rivers, it is a question how great expenditures municipalities should make to accomplish this end. It is the duty of the engineer to weigh the good to be accomplished, on the one hand, against the cost of producing the results, upon the other.

The finding of the Royal Commission, with respect to bacterial contamination of streams used as sources of water supply, is pertinent to this discussion:

> "We are satisfied that rivers generally, those traversing agricultural as well as those draining manufacturing or urban areas, are necessarily exposed to other pollutions besides sewage, and it appears to us, therefore, that any authority taking water from such rivers for the purpose of water supply must be held to be aware of the risks to which the water is exposed, and that it should be regarded as part of the duty of that authority, systematically and thoroughly, to purify the water before distributing it to their customers. Apart from the question of drinking waters, we find no evidence to show that the mere presence of organisms of a noxious character in a river constitutes a danger to public health or destroys the amenities of the river. Generally speaking, therefore, we do not consider that in the present state of knowledge we should be justified in recommending that it should be the duty of a local authority to treat its sewage so that it should be bacteriologically pure." (Royal Comn. on Sew. Disp., Fifth Rept., 1908).

Attention has been directed to the complications arising in problems of sewage disposal, on account of the use of combined sewers. The difficulties and expense of handling and treating sewage from a combined system raise some very serious questions in many localities. There again it is important to arrive at a balance between value and cost. Where it is permissible to discharge the excess flow over and above the normal quantity of sewage, directly into the river or other body of water, without treatment, there is grave doubt if large expenditures are warranted to produce clear and sparkling effluents of low bacterial content, while less expensive treatment will result in adequate purification to prevent putrefaction and excessive bacterial contamination.

Professor Case suggests the question of controlled dilution. That is an exceedingly important subject and one which is very rarely dealt with. Dilution can be controlled in several ways. Mr. Reppert mentioned one,—distributing the sewage throughout the stream. For three or four years we have been directing for a large tannery the disposal of its industrial wastes in a very small stream. At the outset the company was confronted with the requirement that it must filter all wastes through sand—which was entirely impracticable as they contained very large quantities of suspended and colloidal solids. The company has under its control several reservoirs holding perhaps 800 000 000 gallons of water which is drawn in proportion to the quantity of settled water turned out. This treatment with the filtration of a portion of the water has prevented a nuisance in the river up to the present time. The wastes and river water are actually measured by means of weirs and the ratio of the two thus kept under absolute control.

In another case a large woolen mill has an exactly similar proposition. There are two reservoirs; one was never drawn upon because the mill authorities were informed that if they opened the flood gates the water would disappear into the ground and it would not go down stream at all. Measuring weirs were installed and sufficient water is now drawn to dilute the waste in such a way that no nuisance has resulted during the last two years.

I think that answers all the questions which have been asked.

THE MATHEMATICAL THEORY OF THE ELASTIC ARCH

By Willis Whited*

Numerous methods have been devised for determining the stresses in hingless arches, almost every writer proposing a different one. They can, however, be gathered into groups, the members of each group differing only in detail. It is proposed in the present paper to present some of the principal methods, giving demonstrations of the general principles of the subject and explanations of such of the main details as are not intelligibly discussed in books which are generally accessible in the English language. The aim will be to present the subject in such a manner that it can be understood without great diffculty by the graduate in civil engineering.

It will be assumed that the reader is familiar with elementary Analytical Geometry and Differential and Integral Calculus, with the ordinary laws of flexure and also with so much Analytical and Graphical Statics, including Influence Lines as is given in ordinary treatises on bridge design. Much of the work admits of the employment of either analytical or graphical methods, but as a rule the graphical method is not sufficiently accurate for long spans.

The methods here given are all based on the ordinary elastic theory, taking no account of the error due to assuming that the segments into which an arch is divided by radial planes is equivalent to a prismatic segment of the same length on the center line. The methods are intended primarily for either plain or reinforced concrete arches. Most of them can be used for steel trussed arches with more or less modification. These modifications will not be discussed here, as the experienced designer will seldom have difficulty in adapting them to any given case.

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Stone and brick arches should, properly be designed according to the elastic theory; although they do not appear to be as a general rule, largely owing to the fact that the spans are short and the unit stresses small. If there is no rupture by tension at any point, they act as elastic arches, however they may be calculated.

In the present paper, the usual assumptions will be made, viz: that plane sections remain plane; that the modulus of elasticity and the changes in temperature are uniform throughout the structure; and that the skewbacks remain absolutely fixed unless otherwise stated. In reinforced concrete arches the difference in modulus of elasticity between steel and concrete must, of course, be considered.

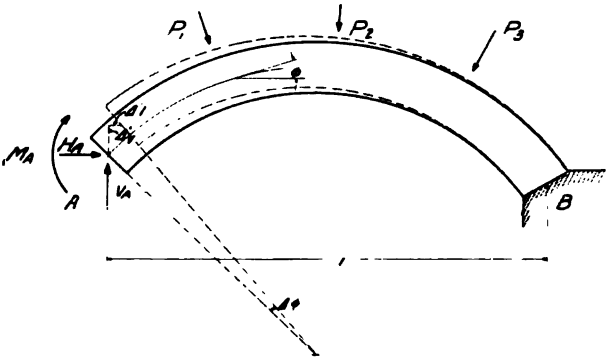

Fig. 1.

Let AB, Fig. 1, represent a hingeless arch without weight, with the left abutment removed. Let

P_1 P_2..... = External forces
$\Delta' l$...... = Horizontal deflection due to P_1 P_2......
$\Delta' v$...... = Vertical deflection due to P_1 P_2........
$\Delta' \phi$...... = Angular deflection due to P_1 P_2........
H_A, V_A, M_A. = Horizontal, vertical and rotating forces required to restore the end A of the arch to its original position. These will obviously be the reactions at the left skewback due to the loads P_1 P_2. ....

The angular deflection of an indefinitely short section dS of the arch due to the moment M_x is

$$\frac{M_x dS}{E\,I}$$

The horizontal, vertical and angular deflection of A due to M_x is

$$\int_0^l \frac{M_x y dS}{E\,I};\quad \int_0^l \frac{x M_x dS}{E\,I};\quad \int_0^l \frac{M_x dS}{E\,I}\quad \text{respectively}$$

in which E = Modulus of elasticity.
I = Moment of interia.
l = Horizontal length of the arch axis.
Let F = Cross sectional area of the arch.
ϕ = Angle between tangent to arch axis and horizontal.

A tangential force N_x acting on an indefinitely short section dS of the arch will compress it an amount equal to

$$\frac{N_x\, dS}{EF}$$

The total horizontal and vertical deflection of A due to N_x is

$$\int_0^l \frac{N_x \cos\phi\, dS}{EF} \text{ and } \int_0^l \frac{N_x \sin\phi\, dS}{EF} \text{ respectively.}$$

The deflection due to transverse shear will not be considered because the transverse shearing stresses are relatively small in amount and the deflection due to them is still smaller, at least in the case of a masonry arch.

The horizontal and vertical deflections of A due to change of temperature are

$$\int_0^l wt \cos\phi\, dS \quad \text{and} \quad \int_0^l wt \sin\phi\, dS \quad \text{respectively,}$$

in which

w = coefficient of expansion
t = rise in temperature in degrees.

The deflection of A due to any force or forces, is as follows:

$$\left.\begin{aligned} \Delta' l &= -\int_0^l \frac{yM_x dS}{EI} + \int_0^l \frac{N_x \cos\phi dS}{EF} - \int_0^l wt \cos\phi dS \\ \Delta' v &= \int_0^l \frac{xM_x dS}{EI} + \int_0^l \frac{N_x \sin\phi dS}{EF} - \int_0^l wt \sin\phi dS \\ \Delta' \phi &= \int_0^l \frac{M_x dS}{EI} \end{aligned}\right\} (1)$$

The following assumptions are made, as shown in Fig. 1:

t is positive.
N_x acts in compression.
M_x acts in clockwise direction.
$\Delta' l$, $\Delta' v$, $\Delta' \phi$ are positive.

If the deflections $\Delta' l$, $\Delta' v$, $\Delta' \phi$ due to P_1 P_2... be determined and placed equal to the corresponding deflections produced by the unknown reactions H_A, V_A, M_A respectively, three equations will be obtained by which H_A, V_A, M_A can be determined, but this process is very laborious and various methods have been devised for shortening the labor. The integrations cannot, in general, be effected exactly and various approximations have been proposed, some of which will be discussed hereafter. When a mathematician encounters a differential expression which he is unable to integrate, three courses are open to him:

1. To give up—this is not admissible in engineering work.

2. To "fudge" the expression into a form which he can integrate. This must be done very carefully lest he introduce errors much larger than he intends. This method is not always practicable; when practicable, it is generally best if successive integration is required, although still greater care must be exercised in this case than in the former case.

3. To apply one of the numerous methods of approximate integration, either graphical or analytical.

It is reassuring to the young engineer to know that at least one of these methods can be applied to practically every definite integral of the first order involving only one independent and one dependent variable, unless the function becomes infinite within the limits of integration. They are also applicable to many other cases.

As both the skew-backs are considered fixed, the deflections due to the applied forces will be equal and opposite to those due to the reactions and if the reactions are included among the forces in equations (1) the right hand members can be placed equal to zero. If, however, any yielding of the skew-backs is to be considered, such deflection must be added to that due to the applied forces.

If the amount and direction of the movement of the skew-backs are known, little difficulty will be found in determining the stresses due to it. It will be found much more convenient to determine these stresses by one operation and the temperature stresses by a second operation, because the latter are both positive and negative.

If we consider both the applied loads and the skew-back reactions to be acting, and neglect the temperature stresses, equations (1) become

$$\left.\begin{aligned} 0 &= \int_0^l \frac{yM_x dS}{EI} - \int_0^l \frac{N_x \cos \phi dS}{EF} \\ 0 &= \int_0^l \frac{xM_x dS}{EI} + \int_0^l \frac{N_x \sin \phi dS}{EF} \\ 0 &= \int_0^l \frac{M_x dS}{EI} \end{aligned}\right\} \dots\dots\dots\dots\dots (2)$$

The direct solution of equations (2) is quite tedious, but can be much shortened by the following method: Let

M_0 = Moment at any point x, considering the arch to be simply supported at the ends.

H = Horizontal reaction at skew-backs = $N_x \cos \phi$.

M = Moment at A.

V = Vertical reaction at A = $N_x \sum_A^x P \dots$ acting vertically.

then

$$M_x = M_0 + M - Hy + Vx \dots\dots\dots\dots\dots\dots\dots (3)$$

The quantity $N_x \sin \phi$ is small and can be neglected in arches of moderate rise so far as its influence on the value of V is concerned. It is, however, easily inserted if desired and does not greatly complicate the calculations.

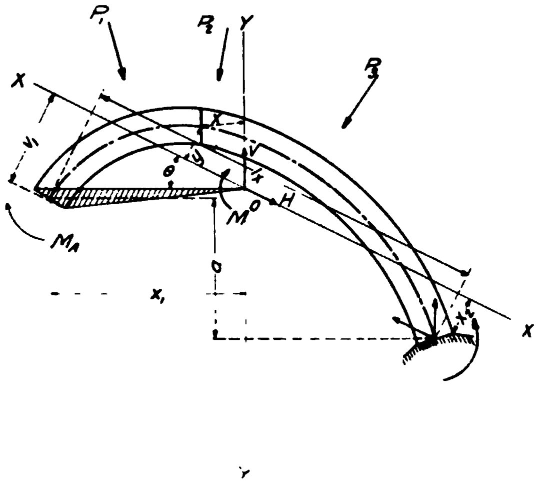

Fig. 2.

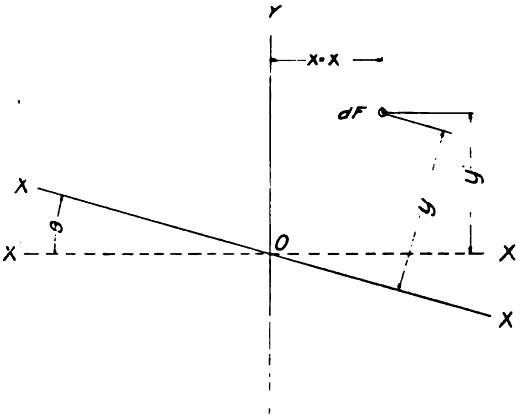

Fig. 3.

Let the coordinate axes be so chosen that

$$\int_0^l \frac{xdS}{I} = \int_0^l \frac{ydS}{I} = \int_0^l \frac{xyds}{I} = O \ldots\ldots\ldots\ldots\ldots \quad (4)$$

i.e., the arch must be divided into short, equal segments dS and then each segment divided by I to determine its *elastic weight.* The center of gravity of its elastic weight will be the origin O in Fig. 2, and if such a value be chosen for θ that the product of inertia vanishes, the position of the axes will be determined. The axis of Y should, as a rule, be vertical. The following method can be used to determine the value of θ.

Let the lever arms of the moments be perpendicular to their respective axes, as in Fig. 3, and let the other dimensions be as shown.

$$\begin{aligned} I_y &= I_y' = \int x^2 dF \\ y &= (y' + x' \tan \theta) \cos \theta \\ I_{x'y'} &= \int x'y'dF \\ I_{xy} &= \int xydF \\ &= \cos \theta \int (x'y' + x'^2 \tan \theta)\, dF \end{aligned}$$

Now if

$$\begin{aligned} I_{xy} &= O \\ \int x'y'dF &= -\tan \theta \int x'^2 dF = -\tan \theta\, I_y \text{ and} \\ \tan \theta &= \frac{-I_{x'y'}}{I_y} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5) \end{aligned}$$

The position of the coordinate axes is independent of the loading on the arch. If we substitute the values of M_x from (3) in equations (2), we shall have

$$c = \int_0^l \frac{M_0 ydS}{EI} - H \int_0^l \frac{y^2 dS}{EI} + V \int_0^l \frac{xy\, dS}{EI} + M \int_0^l \frac{yds}{EI} - H \int_0^l \frac{dS}{EF}$$

$$o = \int_0^l \frac{M_0 xdS}{EI} - H \int_0^l \frac{xydS}{EI} + V \int_0^l \frac{x^2 dS}{EI} + M \int_0^l \frac{xdS}{EI}$$

$$c = \int_0^l \frac{M_0 dS}{EI} + M \int_0^l \frac{dS}{EI}$$

Substituting the conditions in equations (4) and reducing, we have

$$\left.\begin{aligned} H &= \frac{\displaystyle\int_0^l \frac{M_0 y dS}{I}}{\displaystyle\int_0^l \frac{y^2 dS}{I} + \int_0^l \frac{dS}{F}} \\ V &= \frac{\displaystyle -\int_0^l M_0 x \frac{dS}{I}}{\displaystyle\int_0^l x^2 \frac{dS}{I}} \\ M &= \frac{\displaystyle -\int M_0 \frac{dS}{I}}{\displaystyle\int \frac{dS}{I}} \end{aligned}\right\} \dots\dots\dots\dots\dots\dots \quad (6)$$

H, V, and M as determined by (6) are applied at O.

$H_A = H \cos \theta$ .... (7)

$V_A = V + H \sin \theta$ .... (8)

$M_x = M_0 + M - Hy + Vx$ as above in .... (3)

$N_x = N_0 + (V_A - \Sigma_A^x P) \sin \phi + H \cos \phi$ .... (9)

in which

N_0 = tangential component at x of a 3-hinged arch of same dimensions.

$M_A = M - Hv_1 + Vx_1$ .... (10)

By means of these formulas all the moments and reactions can be obtained and the stresses in any section can be determined either graphically or analytically for any loading, or a unit load can be assumed at as many points as desired and influence lines laid out.

This method is much used in Germany and other European countries. It was originated, I understand, by Prof. Muller-Breslau, in a somewhat modified form. It is quite simple and can be made as accurate as desired by dividing the arch into a sufficiently large number of segments and performing the integrations accurately. If the axis of the arch is an arc of a circle, it will be more convenient to divide the arch axis into equal segments; otherwise, it may be easier to divide equally the horizontal line connecting the centers of the skew-backs and replace *ds* with *sec* θ *dx*. The integrations should be effected by means of the following formulas:

$$\int ydx = \tfrac{1}{3}dx(y + 4y_1 + 2y_2 + 4y_3 + \ldots + 4y_{n-1} + y_n) \ldots\ldots (11)$$

In this case n must be even. It is known as Simpson's Rule.

$$\int ydx = \tfrac{3}{8}dx(y + 3y_1 + 3y_2 + y_3) \ldots\ldots (12)$$

This is not quite so accurate as (11) but if the number of divisions is odd, three can be summed up by (12) and the remainder by (11).

$$\int ydx = \tfrac{2}{45}dx(7y + 32y_1 + 12y_2 + 32y_3 + 7y_4) \ldots\ldots (13)$$

This is more accurate than either of the above, but requires that the number of segments be divisible by 4.

$$\int ydx = \tfrac{3}{10}dx(y + 5y_1 + y_2 + 6y_3 + y_4 + 5y_5 + y_6) \ldots\ldots (14)$$

This is more accurate than any of the preceding, but requires that the number of segments be divisible by 6. They can, of course, be repeated for a larger number of segments, in which case the coefficients for (12), (13) and (14) become respectively:

1, 3, 3, 2, 3, 3, 2.......3, 1.
7, 32, 12, 32, 14, 32, 12, 32, 14.....32, 7.
1, 5, 1, 6, 1, 5, 2, 5, 1, 6, 1, 5, 2 .....5, 1.

If the arch is symmetrical and the loading vertical, the calculations are greatly simplified and it is only necessary to make the summations for one-half the arch. If the lines of action of the loading forces lie in various directions, it will generally be best to consider the horizontal and vertical components separately.

Graphical methods may be used for effecting these integrations but they are less accurate and scarecely less laborious. The best treatises on graphical statics give methods for constructing not only statical moments, but also moments of inertia and products of inertia.

It will be found more convenient to find the stresses due to N in a separate operation, but the results are not quite so accurate unless the arch has quite a moderate rise. These are known as the stresses due to rib shortening. Temperature stresses are obtained much more easily in a separate operation. The same may be said of stresses due to movement of the skew-backs. If it is required to determine the stresses due to the elastic deflection of the skew-backs, caused by the thrust of the arch, or arches, the problem becomes quite complex and will not be discussed at the present time.

If we refer the arch to coordinate axes having the origin at the crown C, remembering that equations (1) are independent of the position of the coordinate axes and neglecting N and $w\,t$, we shall have

$$\Delta x = \int \frac{M_x y dS;}{EI} \quad \Delta y = \int \frac{x M_x dS;}{EI} \quad \Delta \theta = \int \frac{M_x dS}{EI} \quad \ldots\ldots (15)$$

If these integrals are taken between the crown and either skew-back, denoting the right and left sections by the subscripts r and l respectively, we shall have

$$\Delta_r x = -\Delta_l x; \quad \Delta_r y = \Delta_l y; \quad \Delta_r \theta = -\Delta_l \theta \ldots\ldots\ldots\ldots (16)$$

whence

$$\left.\begin{aligned} \int \frac{M_{lx} y dS}{EI} + \int \frac{M_{rx} y dS}{EI} &= 0 \\ \int \frac{x M_{lx} dS}{EI} - \int \frac{x M_{rx} dS}{EI} &= 0 \\ \int \frac{M_{lx} dS}{EI} + \int \frac{M_{rx} dS}{EI} &= 0 \end{aligned}\right\} \ldots\ldots\ldots\ldots (17)$$

Substituting the value of M_x from (3) and remembering that V is positive for the right side and negative for the left side, we have, omitting the constant E,

$$\left.\begin{aligned} \int \frac{M_o y dS}{I} + M \int \frac{y dS}{I} - H \int \frac{y^2 dS}{I} &= 0 \\ \int \frac{M_{ol} x dS}{I} - \int \frac{M_{or} x dS}{I} - V \int \frac{x^2 dS}{I} &= 0 \\ \int \frac{M_o dS}{I} + M \int \frac{dS}{I} - H \int \frac{y dS}{I} &= 0 \end{aligned}\right\} \ldots\ldots (18)$$

Solving for H, V and M, we have

$$\left.\begin{aligned} H &= \frac{\int \frac{dS}{I} \int \frac{M_0 y dS}{I} - \int \frac{M_0 dS}{I} \int \frac{y dS}{I}}{\left(\int \frac{y dS}{I}\right)^2 - \int \frac{dS}{I} \int \frac{y^2 dS}{I}} \\ V &= \frac{\int \frac{M_{0l} x dS}{I} - \int \frac{M_{0r} x dS}{I}}{\int \frac{x^2\, dS}{I}} \\ M &= \frac{H \int \frac{y dS}{I} - \int \frac{M_0 dS}{I}}{\int \frac{dS}{I}} \end{aligned}\right\} \ldots\ldots\ldots (19)$$

To determine the temperature stresses we place

$\Delta' l = O$ and $N_x = H \cos \phi$

in the first and last of equations (1) and place the origin at O and have

$$M_x = M_t + H_t y$$

$$\int_0^l wt \cos \phi ds = wtl$$

in which M_t and H_t respectively are the moments and thrusts at A due to change of temperature. Then

$$M_t \int_0^l \frac{y dS}{EI} + H_t \int_0^l \frac{y^2 dS}{EI} + H_t \int_0^l \frac{\cos^2 \phi dS}{EF} = wtl$$

$$M_t \int_0^l \frac{d\,S}{EI} + H_t \int_0^l \frac{y dS}{EI} = O$$

whence

$$\left.\begin{aligned} H_t &= \frac{wtl \int_0^l \frac{d\,S}{EI}}{\int_0^l \frac{y^2 dS}{EI} \int_0^l \frac{d\,S}{EI} + \int_0^l \frac{\cos^2 \phi dS}{EF} \int_0^l \frac{d\,S}{EI} - \left(\int_0^l \frac{y dS}{EI}\right)^2} \\ M_t &= \frac{-H_t \int_0^l \frac{y dS}{I}}{\int_0^l \frac{d\,S}{I}} \end{aligned}\right\} (20)$$

The stresses due to rib shortening from thrust can be determined from these formulas by placing N_x in the first of equations (1) equal to $H \cos \phi$ and neglecting the other terms, thus obtaining

$$\Delta l = \int_0^l \frac{H \cos^2 \phi dS}{EF} \quad \dots\dots\dots\dots \quad (21)$$

Substituting the value of Δl thus found in place of wtl in equations (20) and from the values of H and M thus obtained, the stresses due to rib shortening are easily determined. This method is due to Prof. Melan. It is somewhat more laborious than the one first given and is no more accurate.

If we assume that the arch axis is parabolic and that

$$\frac{\cos \phi}{I} \text{ is constant}$$

thus making

$$\frac{d\,S}{I} = \frac{d\,x}{I_0}$$

I_0 being constant, which can be done without great error if the arch has a low rise and is either segmental or parabolic, we shall

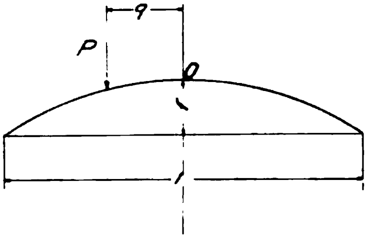

Fig. 4.

have, placing the origin of coordinates O, at the crown of the arch, Fig. 4,

$$y = \frac{4fx^2}{l^2}$$

$$M_0 = -P\,(x-q)$$

$$\int_0^l \frac{d\,S}{I} = \int_0^l \frac{d\,x}{I_0} = \frac{l}{I_0}$$

$$\int_0^l \frac{ydS}{I} = 2\frac{4f}{l^2 I_0} \int_0^{\frac{l}{2}} x^2 dx = \frac{fl}{3\,I^{\circ}}$$

$$\int_0^l \frac{y^2dS}{I} = 2\,\frac{16\,f^2}{l^4\,I_0}\int_0^l x^4dx = \frac{f^2l}{5I^{\circ}}$$

$$\int_0^l \frac{x^2\,dS}{I} = 2\,\frac{1}{I}\int_0^{\frac{l}{2}} x^2dx = \frac{l^3}{12I_0}$$

$$\int_0^l \frac{M_0dS}{I} = \frac{-P}{I_0}\int_q^{\frac{l}{2}} (x-q)dx = -\frac{P}{2I_0}\left(\frac{l}{2}-q\right)^2$$

$$\int_0^l \frac{M_0ydS}{I} = -\frac{4\,Pf}{l^2I_0}\int_q^{\frac{l}{2}} (x-q)x^2dx = \frac{-Pf}{48l^2I_0}(3l^4-8ql^3+16q^4)$$

$$\int_0^l \frac{M_0xdS}{I} = -\frac{P}{I_0}\int_q^{\frac{l}{2}} (x-q)xdx = -\frac{P}{24\,I_0}(l^3-3ql^2+4q^3)$$

Substituting these in (19) and reducing, remembering that the expression for M_0 is based on the assumption that the arch is fixed at both ends and divided at the crown, we have

$$\left.\begin{aligned} H &= \frac{15\,lP}{64f}\left(1-\frac{4q^2}{l^2}\right)^2 \\ V &= -\frac{P}{2}\left(1+\frac{q}{l}\right)\left(1-\frac{2q}{l}\right)^2 \\ M &= Pq\left[\tfrac{1}{8}\left(1-\frac{2q}{l}\right)^2-\tfrac{5}{64}\left(1-\frac{4q^2}{l^2}\right)^2\right] \end{aligned}\right\}\ldots\ldots (22)$$

remembering that q is negative if the load is to the right of C.

From these formulas the influence lines can be laid off with little difficulty, or other methods can be used.

If this method is used, the stresses due to rib shortening and changes in temperature must be calculated separately.

As will be seen, the calculations involved in this method are much the simplest of any of those given. It is, however, the least accurate of any and is not applicable to unsymmetrical arches. It should be used only on short spans of moderate rise.

Some writers divide the arch into sections in such a manner that

$$\frac{d\,S}{I} \text{ is constant.}$$

This greatly simplifies the integrations in (19) and (20) but, as the work of so dividing the arch axis is considerable, no great economy of time is thereby effected. The result, however, is considerably more accurate than would be obtained by the same number of equal divisions, owing to the fact that the more flexible portions of the arch are divided into the shortest sections. Formulas (11)—(14) can be applied in this case also.

Prof. Cain has devised a very ingenious analysis of the elastic arch, dividing the arch into segments according to the method just mentioned. Graphical solutions are quite complicated and must be carried out with great accuracy in order to avoid important errors, unless the length of span is quite moderate.

Prof. Howe has devised a method which gives excellent results and without an unreasonable amount of labor for certain types of symmetrical arches. His development is replete with difficult mathematical work, at which he is wonderfully skillful. His formulas are rather formidable but by a very ingenious system of tables, which he has prepared, the work is greatly facilitated. His method will not be given here.

Mr. Balet has discovered that quite a wide range of forms of symmetrical arches can be solved by formulas (22) with a fairly high degree of accuracy by substituting a parabolic arch whose axis encloses the same area as the arch in question, and from that determining the skew-back reactions which can be used in deducing the stresses in the actual arch. This method is an improvement on that using formulas (22).

Prof. Ritter of Zurich and his successors have developed a very ingenious method for determining the skew-back reactions in an elastic arch by means of the Ellipse of Elasticity. The method is excellent and, although no more convenient for the solution of simple cases than those mentioned above, can be used for a very wide range of problems which scarcely admit of solution by any of the above methods. It appears to be little known in this country, chiefly, perhaps, because the writers on the subject have made free use of projective geometry and modern analytical geometry; branches that are seldom taught to undergraduate engineers on this side of the ocean. As will be seen, the subject can be very readily developed by the ordinary methods of Cartesian geometry with the aid of a few theorems in advanced mechanics, including the Ellipse of Inertia. We will first demonstrate these fundamental theorems.

If a point rotate about two other points at the same time, its resultant angular rotation is equal to the sum of the com-

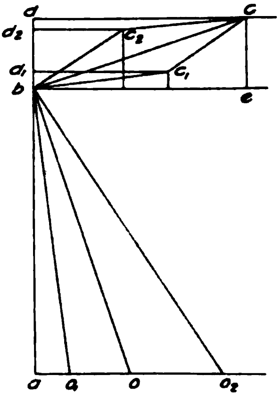

Fig. 5.

ponent angular rotations and its resultant center of rotation is on the line joining the component centers of rotation and at a distance from each inversely proportional to the respective angles of rotation.

Let b be the rotating point, see Fig. 5, and o_1, o_2 the centers of rotation, bc_1 and bc_2 represent indefinitely small simultaneous component rotations. Then, if bc_1, cc_2 is a parallelogram, bc will be the resultant rotation according to the principle of the parallelogram of velocities.

Let

$$\Delta\phi_1 = \frac{bc_1}{bo_1} \text{ and } \Delta\phi_2 = \frac{bc_2}{bo_2}$$

be the simultaneous angles of rotation. Since bc_1 cc_2 is a parallelogram

$$bd_1 = d_2d;\ be_1 = e_2e;\ bd_2 = d_1d \text{ and } be_2 = e_1e$$

or

$$bd_1 + bd_2 = bd \quad \text{and} \quad be_1 + be_2 = be$$

By similar triangles

$$\frac{bc_1}{bo_1} = \Delta\phi = \frac{be_1}{ab} \text{ and } \frac{bc_2}{bo_2} = \Delta\phi_2 = \frac{be_2}{ab}.$$

Adding

$$\Delta\phi_1 + \Delta\phi_2 = \frac{be_1 + be_2}{ab} = \frac{be}{ab} = \frac{bc}{bo}\text{, or}$$

$$bo(\Delta\phi_1 + \Delta\phi_2) = bc = \text{resultant rotation} \quad \ldots\ldots\ldots (23)$$

Therefore *bo* is the radius and *o* the center of the resultant rotations and

$$\Delta\phi_1 + \Delta\phi_2 = \Delta\phi$$

is the resultant angle of rotation. Further

$$\frac{bc_1}{bo_1} = \Delta\phi_1 = \frac{bd_1}{ao_1} \quad \text{and} \quad \frac{bc_2}{bo_2} = \Delta\phi_2 = \frac{bd_2}{ao_2},$$

also $\frac{bc}{bo} = \Delta\phi = \frac{bd}{ao}$ whence

$$ao_1 \times \Delta\phi_1 = bd_1;\ ao_2 \times \Delta\phi_2 = bd_2;\ ao \times \Delta\phi = bd.$$

Adding

$$ao_1 \times \Delta\phi_1 + ao_2 \times \Delta\phi_2 = bd_1 + bd_2 = bd = ao \times \Delta\phi = ao \times \Delta\phi_1 + ao \times \Delta\phi_2$$

transposing

$$ao \times \Delta\phi_1 - ao_1 \times \Delta\phi_1 = ao_2 \times \Delta\phi_2 - ao \times \Delta\phi_2 \text{, or}$$

$$(ao - ao_1)\,\Delta\phi_1 = (ao_2 - ao)\,\Delta\phi_2 \text{, or } oo_1 \times \Delta\phi_1 = oo_2\,\Delta\phi_2 \ldots\ldots\ldots (24)$$

If there are three simultaneous centers of rotation the total angular rotation will evidently be the sum of the component angular rotation and the resultant center of rotation will be determined by connecting the resultant center of two component centers with the third center and so on. In other words, if a weight proportional to its angle of rotation be given to each component center the center of gravity of all the component centers will be the resultant center of rotation.

There are seven possible ways in which an elastic bar can be deflected by external forces, viz:

1. Direct compression or tension.
2. Shear.
3. Bending.
4. Combined compression, or tension, and shear.
5. Combined compression, or tension, and bending.
6. Combined shear and bending.
7. Combined compression, or tension, shear and bending.

We will consider these in their order:

1. If an indefinitely short section, ΔS, of a bar be subjected to a direct axial force the deflection will be in a straight line, or in an arc of a circle whose center is at an infinite distance perpendicular to the axis of the bar.

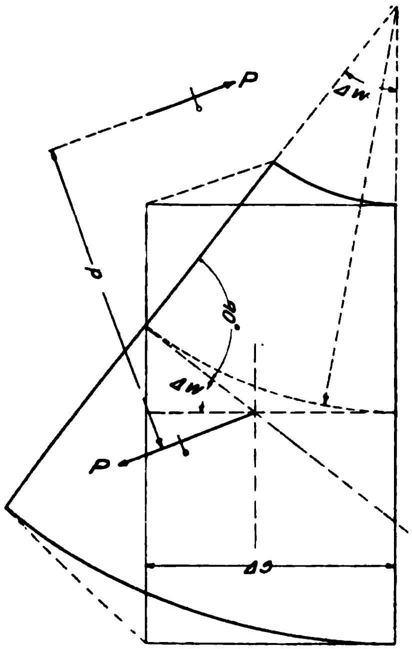

Fig. 6.

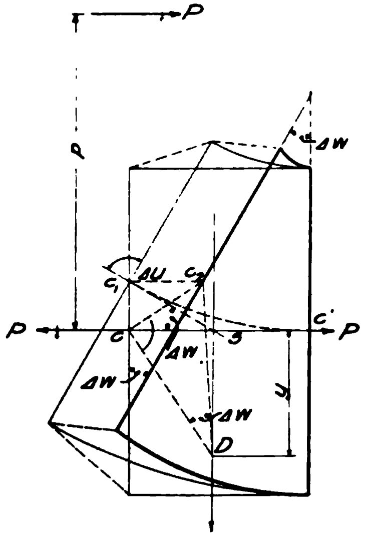

Fig. 7.

2. If a section, ΔS, of a bar be subjected to a shearing force its deflection will be perpendicular to the axis, or in the arc of a circle whose center is at an infinite distance in the line of the axis of the bar

$$\Delta v = \frac{Q\,\Delta S}{E'F}$$

3. If a section, ΔS, of a bar is subjected to a bending force its end will describe an arc ΔW whose radius is

$$\frac{\Delta S}{2}$$

as in Fig. 6 and

$$\Delta W = \frac{M\,\Delta S}{EI}$$

4. If a section, ΔS, of a bar is subjected to a combined axial and shearing force, its end will be deflected in the direction of the component deflections, or in the arc of a circle whose center is at an infinite distance perpendicular to the line of the resultant. The two deflections are

$$\frac{P\,\Delta S}{EF} \quad \text{and} \quad \frac{Q\,\Delta S}{E'F}$$

5. If a section, ΔS, of a bar is subjected to combined axial and bending force, let the segment CC', Fig. 7, be acted upon by the force P acting at a distance p from the axis of the

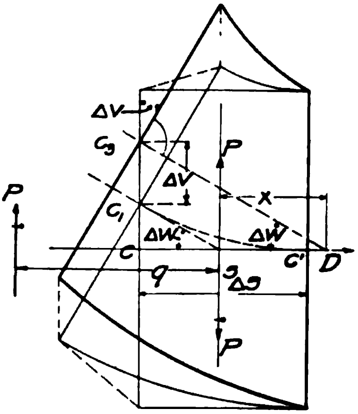

Fig. 8.

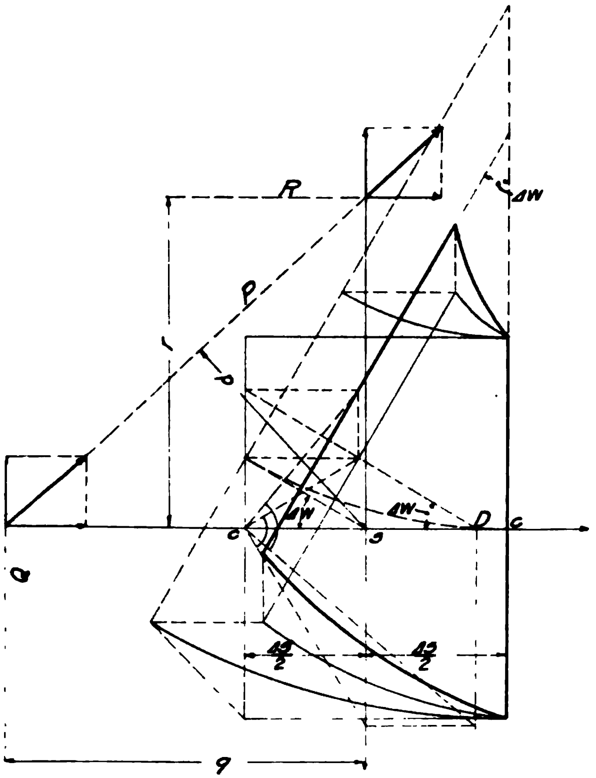

Fig. 9.

segment and parallel thereto. It can be resolved into the couple $P\ p$ and the force P in the axis of the segment. The couple $P\ p$ deflects C to C_1, while the axial force P deflects C_1 to C_2. Draw CC_2 and CD perpendicular to it. Draw C_2D. The center of rotation of CC_1 is S, while the center of rotation C_1C_2 is as the line SD at an infinite distance. The resultant center is, therefore, on the line SD at the point D. By similar triangles $C_1\ CC_2$ and $C\ D\ S$,

$$CC_1 : CC_2 :: CS : CD \quad \text{or} \quad CC_1 : CS :: CC_2 : CD$$

$$SD = \frac{SC \times C_1C_2}{CC_1} = y = \frac{\Delta S\,\Delta U}{\Delta S\,\Delta W} = \frac{\Delta U}{\Delta W} = \frac{P\,\Delta S}{EF} \times \frac{EI}{M\,\Delta S} = \frac{PI}{FM} = \frac{I}{PF}$$

whence

$$yp = \frac{I}{F} = i_2\ ; \quad y = \frac{i_2}{p} \ldots\ldots\ldots\ldots \quad (25)$$

the radius of gyration of the section being i. Hence, since C_2CD and C_1CS are right angles, the two triangles C_1CS and CC_2D are similar and the angles

$$C_1SC = CDC_2 = \Delta W.$$

6. If a section, ΔS, of a bar is subjected to a combined bending and shearing stress, the center of rotation due to the resultant deflection is as shown in Fig. 8 and is on the axis of the bar at a distance SD from the center

$$x = SD = \frac{\Delta S \Delta V}{\Delta S \Delta W} = \frac{\Delta V}{\Delta W} = \frac{Q \Delta S}{E'F} \times \frac{EI}{M \Delta S} = \frac{EI}{E'Fq}$$

whence

$$xq = \frac{E}{E'} \times i^2 \quad \text{and} \quad x = \frac{i^2 E}{E'q} \ldots\ldots\ldots\ldots \quad (26)$$

7. If a section, ΔS, of a bar is subjected to combined axial, shearing and bending stresses the angle of rotation due to

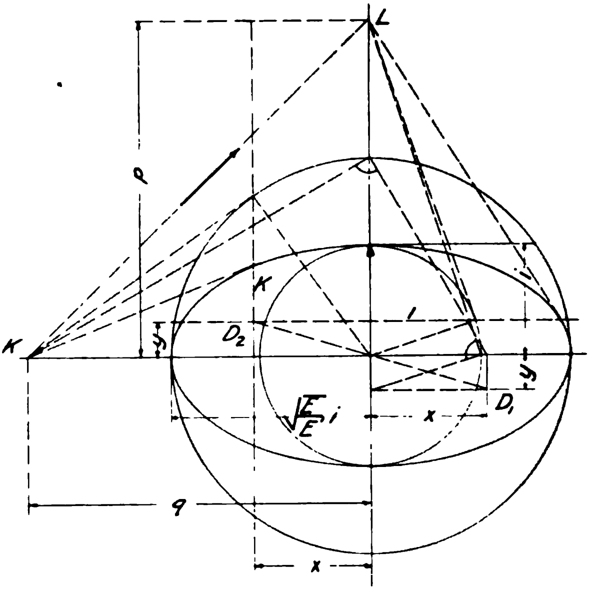

Fig. 10.

bending equals ΔW those due to shear and axial stress equal zero. The resultant angle of rotation, therefore, equals ΔW.

Referring to Fig. 9, we find the construction to be a combination of Figs. 7 and 8 and the same values for x and y will hold.

As will readily be seen from Fig. 10, if an ellipse be described having i as a minor axis and

$$\sqrt{\frac{E}{E'}}\times i$$

as a major axis the polar of the point L distant p from the center of the ellipse will be the line l at a distance

$$\frac{i^2}{p}=y$$

above the major axis; while the polar of point K distant q from the center of the ellipse will be the line k distant

$$\frac{i_2E}{E'q}=x$$

to the left of the minor axis. The intersection D_2 of l and k will, therefore, be the pole of the line KL. The center of rotation due to any force R acting along the line KL will be at D_1 whose coordinates are the same as those of D_2 with their signs changed, see (25) and (26). The point D_1 is, therefore, called the antipole of the line R. We have, therefore, the theorem:

If a force R acts on an indefinitely short section of an elastic bar fixed at one end, every part of the free end of the bar will rotate about a point which is the antipole of the line of action of the force R referred to an ellipse, whose center is the center of the given section and whose major axis is in the axis of the given bar. The length of the semi-minor axis equals the radius of gyration i of the given section and the length of the semi-major axis equals

$$\sqrt{\frac{E}{E'}}\times i.$$

This ellipse is called the ellipse of elasticity and depends entirely upon the dimensions and elastic properties of the bar. The angle of rotation

$$\Delta W=\frac{M\,\Delta S}{EI}$$

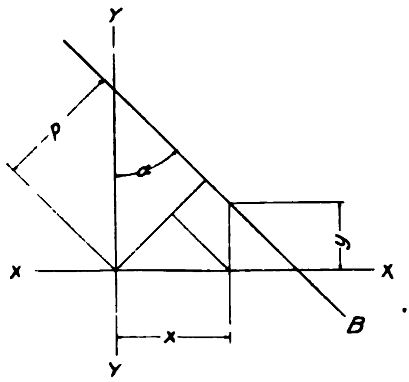

Fig. 11.

We will now develop some principles of the Ellipse of Inertia, which will be useful later. The equation of any straight line referred to rectangular coordinate axes can be placed in the form

$$x \cos \alpha + y \sin \alpha = p$$

in which p, as will readily be seen by Fig. 11, is the distance of the line from the origin of coordinates.

The equation of the tangent to an ellipse referred to its principal axes is

$$\frac{xx^1}{a^2} + \frac{yy^1}{b^2} = 1.$$

If this equation be compared with the equation of a straight line given above it will be seen that

$$\frac{x'}{a^2} = \frac{\cos \alpha}{p} \; ; \; \frac{y'}{b^2} = \frac{\sin \alpha}{p} \text{, or}$$

$$x' = \frac{a^2 \cos \alpha}{p} \; ; \; y' = \frac{b^2 \sin \alpha}{p}$$

If we substitute these values of x' and y' in the equation of the ellipse we shall have

$$\frac{a^4 \cos^2 \alpha}{a^2 p^2} + \frac{b^4 \sin^2 \alpha}{b^2 p^2} = 1\text{, or}$$

$$a^2 \cos^2 \alpha + b^2 \sin^2 \alpha = p^2 \ldots\ldots\ldots\ldots (27)$$

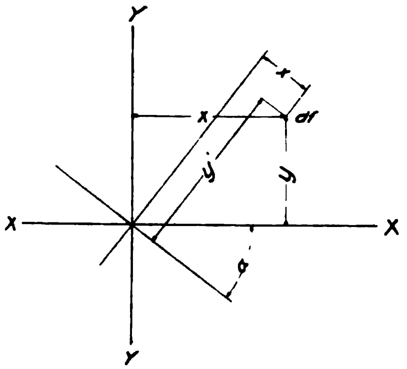

Fig. 12.

If dF represent an element of the area of a surface the moments of inertia of the surface about any two rectangular axes will be

$$I_x = \int y^2 dF \ ; \quad I_y = \int x^2 dF$$

If the surface be referred to another pair of rectangular axes, making an angle α with the first and having the same origin, we shall have

$$x' = x \cos \alpha - y \sin \alpha$$
$$y' = x \sin \alpha + y \cos \alpha$$

Referring to Fig. 12:

$$I_y' = \cos^2\alpha \int x^2 df + \sin^2\alpha \int y^2 df - 2 \sin \alpha \cos \alpha \int xydf$$
$$I_x' = \sin^2\alpha \int x^2 df + \cos^2\alpha \int y^2 df + 2 \sin \alpha \cos \alpha \int xydf$$

If the axes XX and YY be so placed that I_x I_y are minimum and maximum respectively

$$\int xydf = 0$$
$$I_y' = \cos^2 \alpha \int x^2 df + \sin^2 \alpha \int y^2 df$$
$$I_{y'} = I_y \cos^2 \alpha + I_x \sin^2 \alpha$$

Dividing through by the area of the surface

$$i'^2_y = i^2_y \cos^2 \alpha + i^2_x \sin^2 \alpha \ldots\ldots\ldots\ldots\ldots (28)$$

in which i and i' are the radii of gyration corresponding to I and I' respectively. This equation is identical in form with (27); hence we can say:

If any plane figure be referred to rectangular coordinate axes passing through its center of gravity and so placed that the moment of inertia of the same figure about the axis of X is a minimum and that about the axis of Y a maximum and an ellipse be constructed on these axes with its semi-axes equal respectively to the corresponding radii of gyration of the figure, the radius of gyration of the figure about any axis passing through the center of the ellipse will be equal to the perpendicular let fall from the center upon a tangent to the ellipse, parallel to the given axis. This ellipse is called the Ellipse of Inertia.

The product of inertia $\int xydf$ vanishes, as above stated. when referred to the principal axes of the figure. When referred to new axes making the angle α with the principal axes, we have:

$$\int x'y'df = \sin\alpha\cos\alpha \int (x^2 - y^2)df + (\cos^2\alpha - \sin^2\alpha)\int xydf$$

Since $\int xydf = 0$ we have

$$\int x'y'df = \sin\alpha\cos\alpha \int (x^2 - y^2)df \quad \text{or}$$

$$I_{x'y'} = \sin\alpha\cos\alpha\,(I_y - I_x)$$

whence, dividing by A, the area of the figure,

$$\frac{I_{x'y'}}{A} = \sin\alpha\cos\alpha\,(i_y^2 - i_x^2)$$

Referring to Fig. 13, it will be shown that

$$m\,i_{x'} = \frac{I_{x'y'}}{A}$$

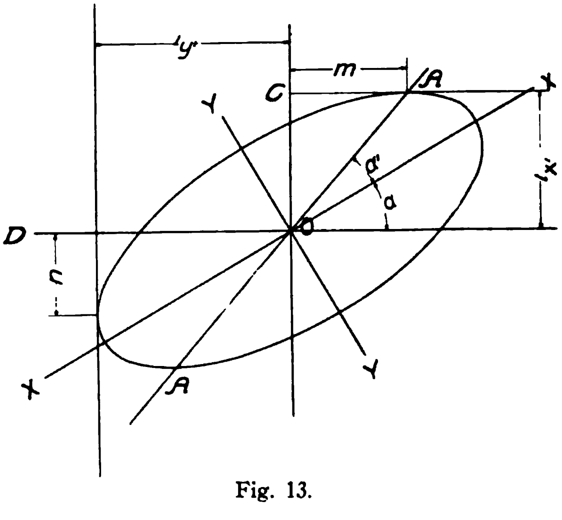

Fig. 13.

Let Fig. 13 represent the ellipse of inertia of a plane figure, XX, YY being its principal axes, DD and AA being a pair of conjugate axes. If a' be the angle AOX and a be the angle XOD we shall have

$$m\,i_x' = \text{area of } OCA = OC \cot CAO$$

$$CAO = AOD = \alpha + \alpha'$$

$$m\,i_{x'} = i^2_{x'} \cot (\alpha + \alpha')$$

By trigonometry

$$\cot (\alpha + \alpha') = \frac{1 - \tan \alpha \tan \alpha'}{\tan \alpha + \tan \alpha'}$$

By analytical geometry

$$\tan \alpha \tan \alpha^1 = \frac{i_x^{\cdot 2}}{i_y^{\cdot 2}} \text{, whence}$$

$$\tan \alpha' = \frac{i_x^{\cdot 2}}{i_y^{\cdot 2} \tan \alpha}$$

Substituting above we have

$$\cot (\alpha + \alpha') = \frac{1 - \dfrac{i_x^{\cdot 2}}{i_y^{\cdot 2}}}{\tan \alpha + \dfrac{i_x^{\cdot 2}}{i_y^{\cdot 2} \tan \alpha}} = \frac{\dfrac{\sin \alpha}{\cos \alpha}\left(i_y^{\cdot 2} - i_x^{\cdot 2}\right)}{\dfrac{i_y^{\cdot 2} \sin^2 \alpha}{\cos^2 \alpha} + i_x^{\cdot 2}}$$

$$= \frac{\sin \alpha \cos \alpha \left(i_y^{\cdot 2} - i_x^{\cdot 2}\right)}{i_y^{\cdot 2} \sin^2 \alpha + i_x^{\cdot 2} \cos^2 \alpha} = \frac{\dfrac{I_{x'y'}}{A}}{i_{x'}^{\cdot 2}} \text{, whence}$$

$$i^2 \cot (\alpha + \alpha') = m i_x' = \frac{I_{x'y'}}{A} \dots\dots\dots\dots\dots\dots (30)$$

Similarly it can be shown that

$$\frac{I_{x'y'}}{A} = n\,i_{y'} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (30\text{-A})$$

The rule that the free end of a beam fixed at one end and under strain rotates about the antipole of the line of action of the straining force referred to the ellipse of elasticity of all that portion of the beam which is under strain, has thus far been proven only for an indefinitely short section of the beam, but if it be required to determine the ellipse of elasticity of a beam of definite length we must proceed according to the principles discussed below.

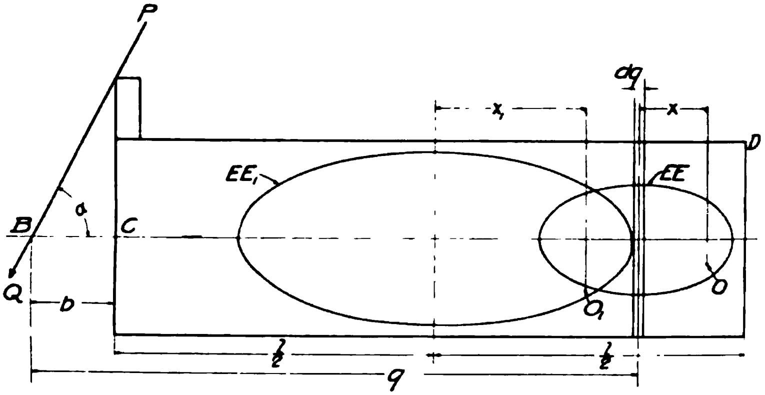

Fig. 14.

Let the prismatic beam *CD*, Fig. 14, be fixed at *D* and stressed by the force *Q* acting along the line *PQ*, the point *P* being rigidly attached to the beam. Let *EE* be the ellipse of elasticity of the indefinitely short section *A* and let EE_1 be the ellipse of elasticity of the whole beam. Let O_1 and *O* be the antipoles of *PQ* with respect to the ellipses EE_1 and *EE* respectively.

The semi-axes of the ellipse *EE* are

$$i \text{ and } i\sqrt{\frac{E}{E'}}$$

By equation (26)

$$x = \frac{i^2 E}{E' q}$$

or placing

$$\frac{i^2 E}{E'} = a^2 \text{ we have}$$

$$x = \frac{a^2}{q}$$

According to the principle enunciated above the antipole O_1 is at the center of gravity of the antipoles of the ellipses of elasticity of all the indefinitely short sections, *dq* of the beam; each antipole being assumed to have a weight proportional to the angle of deflection due to the stress on the corresponding section, *dq* of the beam. This deflection is evidently proportional to the lever arm q of the vertical component of the force Q. If we take the origin of moments at B, the abscissa of O is

$$q + x$$

and the moment of the assumed weight of the deflection will be

$$q\,(q + x) = q\left(q + \frac{a^2}{q}\right) = q^2 + a^2$$

and the distance

$$BO_1 = b + \frac{l}{2} + x_1$$

from B to this center of gravity will be equal to the sum of these moments divided by the total deflection of the beam, which will be proportional to

$$\int_b^{b+l} q\,d\,q, \text{ or}$$

$$BO_1 = \frac{\int_b^{b+l}(q^2+a^2)dq}{\int_b^{b+l} q\,d\,q} = \frac{\frac{l^2}{3} + lb + b^2 + a^2}{b + \frac{l}{2}}$$

and the antipolar distance

$$x_1 = \frac{\frac{l^2}{3} + lb + b^2 + a^2}{b + \frac{l}{2}} - \left(b + \frac{l}{2}\right) = \frac{a^2 + \frac{l^2}{12}}{b + \frac{l}{2}}$$

The semi-major axis of the ellipse EE_1 (see above) equals

$$\sqrt{x_1\left(b + \frac{l}{2}\right)} = \sqrt{a^2 + \frac{l^2}{12}} = \sqrt{i^2\frac{E}{E'} + \frac{l^2}{12}}$$

Assuming

Depth of beam = 1, and

$$\frac{E}{E'} = 2.5$$

$$\frac{i^2\,E}{E'} = 0.20833$$

If $l = 10$; $\frac{l^2}{12} = 8.3333$; $\sqrt{8.3333 + 0.20833} = 2.9226$

If we neglect a this becomes $\sqrt{8.3333} = 2.8867$ an error of 1.23%.

If $l = 30$; $\sqrt{\frac{l^2}{12}} = 8.6603$; $\sqrt{a^2 + \frac{l^2}{12}} = 8.6723$ an error of 0.136% if we neglect a.

It is thus seen that in ordinary cases, the error due to ignoring

$$\frac{i^2 E}{E^1}$$

is negligible, but where l is relatively small and it is desired to include this quantity, its inclusion does not greatly complicate the calculations. Omitting this quantity we have the semi-major axis of the ellipse

$$= \sqrt{\frac{l^2}{12}}$$

which is the radius of gyration of the longitudinal section of the beam.

The ordinate of the antipole $O = \dfrac{i^2}{q \tan \alpha}.$

The angular deflection due to the elasticity of any element, dq, is proportional to $q \sin \alpha \, dq$. The total moment of these deflections about B equals

$$\int_b^{b+l} \frac{i^2}{q \tan \alpha} q \sin \alpha \, dq = \int_b^{b+l} i^2 \cos \alpha \, dq$$

If we divide this as before by the total deflection,

$$\int_b^{b+l} q \sin \alpha \, dq$$

we shall have for the ordinate of the antipole of the ellipse of elasticity $(EE)_1$ of the whole beam

$$\frac{\int_b^{b+l} i^2 dq}{\int_b^{b+l} q \tan \alpha \, dq} = \frac{i^2 l}{\frac{\tan \alpha}{2}\left[(b+l)^2 - b^2\right]} = \frac{i^2}{\left(b + \frac{l}{2}\right) \tan \alpha}$$

which is the ordinate of the antipole of PQ with reference to EE_1.

The ordinate of PQ at the center of the beam is

$$\left(b + \frac{l}{2}\right) \tan \alpha$$

and multiplying it by

$$\frac{i^2}{\left(b + \frac{l}{2}\right) \tan \alpha}$$

we have i^2 which equals the semi-minor axis of the ellipse EE_1.

It will thus be seen that the ellipse of elasticity of any beam, either straight or curved is very nearly the same as the ellipse of inertia of the elastic weight of the beam.

In applying this theory to the elastic arch, it will generally be advantageous to take the origin of coordinates at the center of gravity of the elastic weight of the arch with the axis of Y parallel to the line of action of the applied loads which will usually be vertical. It will be necessary to determine the ellipse of elasticity of each segment of the arch extending from the point of application of each load to the skew-back which is assumed to be fixed. If a moving load is to be provided for, it will generally be best to determine the maximum stresses by means of influence lines.

In ordinary symmetrical bridge arches, the principal ellipse will have its major axis horizontal, but this will not be the case with the segmental ellipses. It will be best to divide the arch into short segments and determine the elastic weight of each segment, then locate the center of gravity of all these elastic weights, pass coordinate axes through them and determine the coordinates of the center of each segment. Then the statical moments, the moments of inertia and the product of inertia of each segment about the principal coordinate axes of the arch, should be determined. These, of course can be added together to obtain the moments, etc., for any required portion of the arch.

The inclinations of the principal axes of the component ellipses may be found as follows:

Let $x\ y$ be the coordinates of any element dF of a figure, the axes being rectangular and passing through the center of gravity of the figure, and $x'\ y'$ the coordinates of the same element referred to other rectangular axis having the same origin and making an angle α with the original axes, then by Fig. 12

$$x' = x \cos \alpha - y \sin \alpha$$

$$y' = x \sin \alpha + y \cos \alpha$$

$$\int x'y'dF = \sin \alpha \cos \alpha \int x^2 dF - \sin \alpha \cos \alpha \int y^2 dF + (\cos^2 \alpha - \sin^2 \alpha) \int xy dF$$

If the new axes coincide with the principal axes of the figure

$$\int x'y'\,dF = 0, \quad \text{and}$$

$$\sin \alpha \cos \alpha \left(\int x^2 dF - \int y^2 dF\right) = -(\cos^2 \alpha - \sin^2 \alpha) \int xy dF$$

or

$$\tfrac{1}{2} \sin 2\alpha \, (I_x - I_y) = \cos 2\alpha \, I_{xy} \text{, whence}$$

$$\tan 2\alpha = \frac{2I_{xy}}{I_x - I_y} \quad \text{(31)}$$

We will now develop formulas for locating the antipole of any given ellipse of elasticity when the position of the polar is given and vice versa.

In Fig. 15, let EE be the given ellipse and $BF = n$, a vertical tangent, EFF' a diameter passing through F and, therefore, conjugate to the vertical diameter $A'C$.

Let EAA' be any straight line intersecting the axes of X and Y at A and A' respectively and K its antipole with reference to the ellipse EE.

Let $BC = i_y$ be the radius of gyration about the axis of Y and KK', AG and $E'E$ be parallel to CY.

Let $F = \int dF$.

By (30—A)

$$i_y n F = I_{xy} \text{ and } FC^2 = EC \times CK' \text{ whence}$$

$$BC^2 = i_y^2 = xE'C = xx_4$$

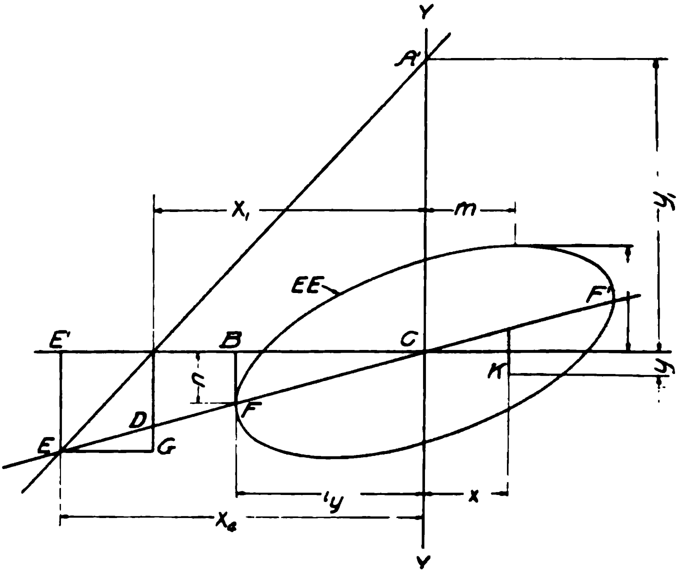

Fig. 15.

$$\frac{i_y}{n} = \frac{EG}{GD} = \frac{x_1}{AD} = \frac{x_4}{AG} = \frac{x_1}{AG} + \frac{EG}{AG} = \frac{x_1}{AG} + \frac{x_1}{y_1}$$

$$AG = \frac{x_1 y_1 n}{i_y y_1 - x_1 n}\,;\ EG = AG \times \frac{x_1}{y_1} = \frac{x_1^2 n}{i_y y_1 - x_1 n}$$

$$x_4 = EG + x_1 = \frac{i_y x_1 y_1}{i_y y_1 - x_1 n}$$

$$x = \frac{i_y^2}{x_4} = \frac{i_y^2}{x_1} - \frac{i_y n}{y_1} = \left(\frac{I_y}{x_1} - \frac{I_{xy}}{y_1}\right) A \text{.........} (32)$$

similarly

$$y = \left(\frac{I_x}{y_1} - \frac{I_{xy}}{x_1}\right) A \text{.........................} (33)$$

Eliminating x_1 and y_1 in turn from these equations, we have

$$y_1 = \frac{i_x^2 i_y^2 - i_1 i_y mn}{i_x x m + i_y^2 y} = \frac{I_x I_y - I_{xy}^2}{A(xI_{xy} + yI_y)} \text{..............} (34)$$

$$x_1 = \frac{I_x I_y - I_{xy}^2}{A(yI_{xy} + xI_x)} \text{........................} (35)$$

Let CD, Fig. 16, be any line intersecting the rectangular axes XX and YY at AB at the distances x, y from the origin. The intersections A' B' with the parallel axes $X'X'$ and $Y'Y'$ at distances b and a from the original axes will evidently be

$$x' = a + x + \frac{bx}{y}\,;\quad y' = b + y + \frac{ay}{x} \text{...........} (36)$$

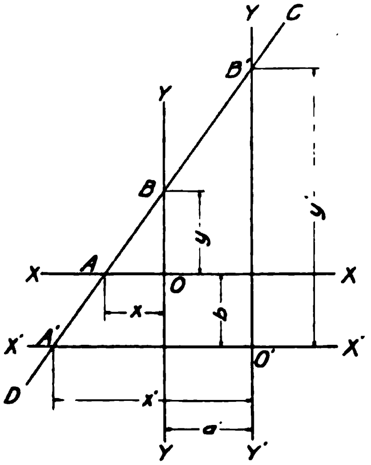

Fig. 16.

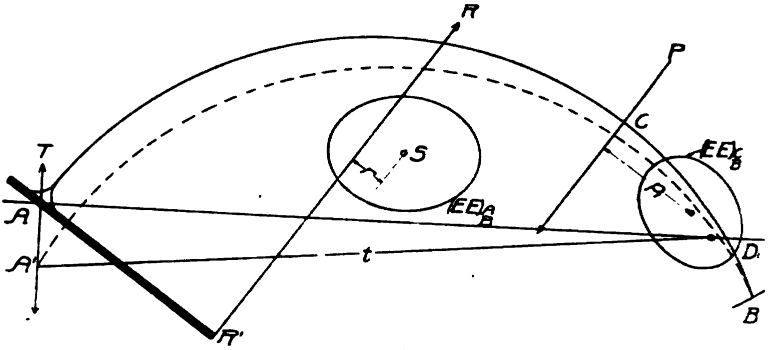

Fig. 17.

To transfer moments and products of inertia from one pair of rectangular axes to another pair parallel to the first, we may use the following formulas:

$$\left.\begin{array}{l} \int(x+a)(y+b)dF = \int xydF + adydF + b\int xdF + ab\int dF \\ \int(x+a)^2dF = \int x^2dF + 2a\int xdF + a^2dF \dots\dots\dots\dots \\ \int(x+a)dF = \int xdF + a\int dF \dots\dots\dots\dots\dots\dots \end{array}\right\} (37)$$

in which $\int xydF$ is the original product of inertia

$\int x^2dF$ = original moment of inertia.

$\int xdF$ = original statical moment.

$\int dF$ = area of figure.

With the aid of these formulas it will be easy to determine the various moments about the principal axes of the arch and to transfer them as required to other parallel axes and to locate the antipolar of any given forces as required.

As shown above, the angle of rotation of the free end of a beam fixed at one end and strained by a force P at a distance p from its elastic center is

$$\Delta W = \Sigma\ Pp\ \frac{\Delta S}{EI}$$

the summation including all that portion of the beam between the point of application of P and the fixed end. Any point rigidly attached to the free end of the beam will evidently describe the same angle. If, therefore, the arch AB, Fig. 17, fixed at B and free at A be strained by a force P the end A will describe an arc

$$AA' = t\,\Delta W = \sum_B^C Pp\frac{\Delta S}{EI}$$

about the point D as a center, D being the antipole of the line of action of the force P referred to the ellipse of elasticity $(EE)_B^C$ of the segment BC of the arch.

If now $R'R$ is the antipolar of the point D with respect to the ellipse of elasticity $(EE)_B^A$ of the whole arch BA any force acting along the line $R'R$ at the point R', which is supposed to be rigidly attached to the arch rib at A will cause the point A to rotate about the point D, the angle of rotation being

$$\sum_B^A Rr\frac{\Delta S}{EI}$$

since R, r, P and p are constant

$$\Sigma Pp\frac{\Delta S}{EI} = Pp\,\Sigma\frac{\Delta S}{EI}$$

$$\Sigma Rr\frac{\Delta S}{EI} = Rr\,\Sigma\frac{\Delta S}{EI}$$

In order that the end of the arch A be brought back from A' to A we must have

$$Rr\sum_B^A \frac{\Delta S}{EI} = Pp\sum_B^C \frac{\Delta S}{EI}\text{, whence}$$

$$R = \frac{Pp\sum_B^C \frac{\Delta S}{EI}}{r\sum_B^A \frac{\Delta S}{EI}} \qquad (38)$$

Thus the reaction R at the left abutment of the arch is determined both in position and intensity.

Stresses due to changes in temperature require a slight modification of the method given above.

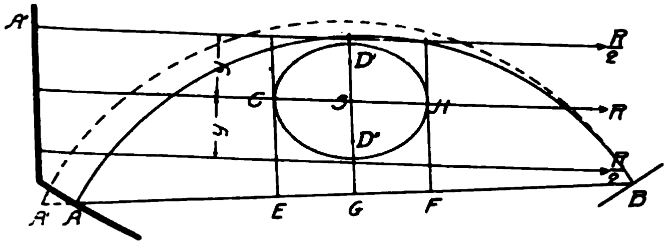

Fig. 18.

If we assume, as before, that the arch is fixed at the end B. Fig. 18, and free to move at the end A, the motion of A will be in a straight line AA', i.e. the center of rotation will be at an infinite distance and its antipolar will pass through the center of the ellipse of elasticity of the arch. The direction of the center will be perpendicular to AB on the line GS, say, and the line of action of the force R required to resist it will be the diameter of the ellipse CH conjugate to GS.

In order to determine its intensity we will assume R to be replaced by two forces parallel to CH, distant y from it, on opposite sides and each equal to $\frac{R}{2}$, y being arbitrary.

Let $D'D''$ be the antipoles of the forces $\frac{R.}{2}$ The deflection $A'\ A$ due to R is

$$D'G\ \frac{Rr}{2}\sum_B^A \frac{\Delta S}{EI} - D''G\ \frac{Rr}{2}\sum_B^A \frac{\Delta S}{EI} = D'S\ \ Rr\sum_B^A \frac{\Delta S}{EI} = SL^2\ \ R\sum_B^A \frac{\Delta S}{EI}$$

whence

$$R = \frac{A'\ A}{SL^2\ \sum_B^A \frac{\Delta S}{E\ I}} \qquad \qquad (39)$$

SL being the semi-diameter of the ellipse and $A'A$ the amount of the expansion.

The same method would, of course, apply in determining the stresses due to a parallel deflection of either or both skew-backs, except that the motion might be in some other direction. If the yielding of the skew-backs is angular, as well as linear, its center of motion must be found. Its antipolar will be the line of the reaction of the skew-back and its force can be determined as above.

Graphical methods may be applied to a considerable extent in the application of the ellipse of elasticity if preferred, but the analytical solutions above given are so simple and so much more accurate that they will generally be found preferable, especially for long-span arches. This method may also be applied to the two-hinged arch but to little, if any, advantage. It is more suitable for the more complex and difficult problems in the elasticity of structures.

DISCUSSION

Mr. C. N. Haggart:* I think this is a very difficult subject for presentation and discussion. I was interested in hearing Mr. Whited compare the different authors and his remarks on those who put the subject most clearly.

I would like to ask if he knows any one English writer who has put this subject concisely in such a way that the graduate engineer not specialized in this work can understand with a reasonable amount of application. I have gone through Cain's method and have read a little of Merriman and Jacoby's books on the subject, and while I did not find either one of them so difficult to understand as I went along. I did find it difficult to remember and apply what I had been over.

Also, in speaking of Cain's method, I would like to ask if there is not some way of dividing the arch—(that is, Cain divides the arch into segments inversely proportional to moments of inertia of the sections of the arch)—in some way as to determine the lengths of sections exactly without having to use the cut-and-try methods.

It seems to me that if writers would first give a general outline of the principles which they intend to apply and would afterwards follow up with the detailed demonstration, that it would be much easier for the reader to understand what he had been over. Mr. Cain in his monograph uses this idea to some extent by carrying out some of the mathematical demonstration in finer print than is used in the body of the book. It would, however, in my opinion, be still more easy of comprehension if a brief outline of the principles involved were given first.

The Author: This subject of the ellipse of elasticity, I neglected to state, has been discussed in English in this way. A paper was presented before the Western Society of Engineers a year ago last May by A. C. Janni.* This paper, however, presupposes a very considerable knowledge of projection geometry.

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*Consulting Structural Engineer, Vandergrift Building, Pittsburgh.

Most of the material in this paper I have obtained from a small pamphlet issued as a supplement to the *Handbuch der Ingenieurwissenschaften,* a German work in the Carnegie Library covering about a yard of shelf. There are quite a large number of supplementary pamphlets issued with it. This is one of them. The author, Dr. Fritz Postuvanschitz, does not use any projective geometry, but uses homogeneous co-ordinates quite freely, and there are some very elegant graphical solutions for portions of the work.

Referring to Professor Cain's method, one of its drawbacks is the difficulty of dividing the arch into segments. The only way I know to divide it is by the cut-and-try method, and that is not very satisfactory. If it is in the form of a circular ring it is quite simple to handle; if it is an ordinary arch it is rather difficult; and if it is a non-symmetrical arch I am not sure whether the solution is possible or not.

There is an English translation of Melan's method that is pretty good, Turneaure and Maurer's book on reinforced concrete contains an ingenious solution of the arch. Nearly all of it is in foot notes. It is in only half a dozen pages.

Merriman and Jacoby's method is the same as used by Johnson in his work on bridges, which assumes that the arch and parabolic moment of inertia vary as the secant of the angle of inclination. That is the least accurate of any of the methods, but it is by far the most convenient to handle. But, as was stated in the paper, none of the authors, so far as I know, have presented more than one method. I have endeavored here to present the principal ones in as clear a manner as possible.

Mr. C. E. Chase: I would like to ask if you have read the translation of Melan's book by Mr. D. B. Steinman?

The Author: His method is applicable to all kinds of arches. It is a little easier to get at than Muller-Breslau's, but the equations are a little more complicated.

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*Journal, Western Society of Engineers, Chicago, 1913, v. 18, p. 329.

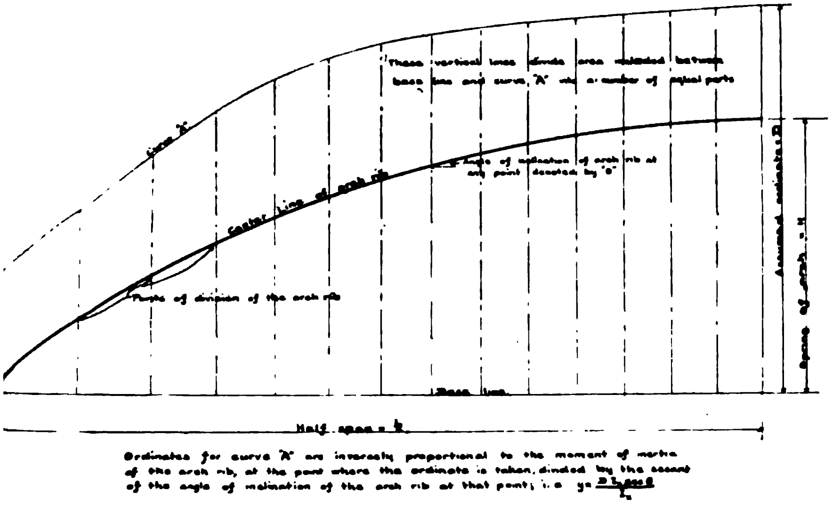
These vertical lines divide area included between base line and curve "A" into a number of equal parts
Curve "A"
Center line of arch rib
Angle of inclination of arch rib at any point denoted by "θ"
Points of division of the arch rib
Base line
Half span = L
Ordinates for curve "A" are inversely proportional to the moment of inertia of the arch rib, at the point where the ordinate is taken, divided by the secant of the angle of inclination of the arch rib at that point; i.e. y =

Fig. 19.

Mr. James S. Martin:* I have been greatly interested in Mr. Whited's paper, and although a press of other duties has prevented my giving it a thorough study, yet I feel that he has added something really worth while to the literature on this subject.

In response to his question as to methods of dividing the arch when applying Professor Cain's method, I would say that I devised a method some years ago which seems to me to be easier than cut-and-try methods.

Referring to Fig. 19: After laying out the center line of the arch rib I plot a curve in which the ordinates are inversely proportional to the moment of inertia at the point where the ordinate is taken divided by the secant of the angle of inclination of the arch rib at that point.

With a planimeter the area of this curve can easily be divided into equal parts by means of vertical lines; the points where these lines cross the center line of the arch are the dividing points.

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*Structural Engineer, Pittsburgh Railways Company.

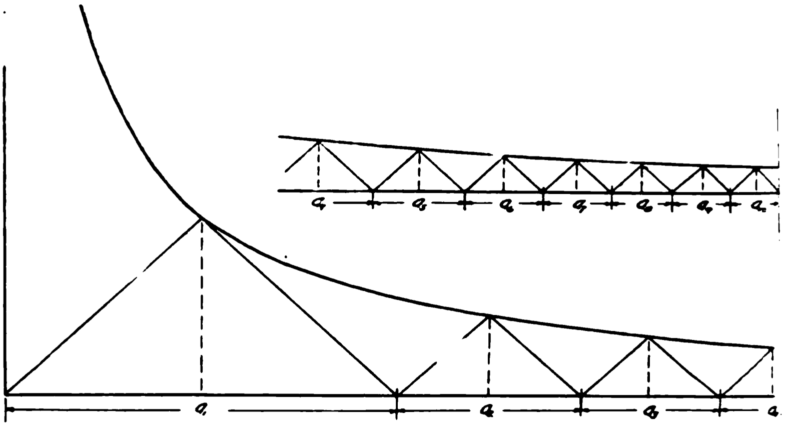

Fig. 20.

Mr. C. E. Chase:* Professor Jacoby at Cornell teaches much the same method as Mr. Martin's. The values of I are plotted as the ordinates of a curve, Fig. 20, the abscissae being the distances of the section at which each value of I is computed, from the end of the arch, measured along the neutral axis. The number of parts into which it is desired to divide the neutral axis of the half span is then decided. Ten parts are commonly used, so chosen that the ratio of the length of each division, ds, to the value of I at its middle, is constant. This is accomplished graphically by drawing a series of isosceles triangles whose vertices are located on the curve previously drawn. Several trials may be needed to secure the proper slope of the sides of these triangles to make the last division end exactly at the crown center.

Mr. James S. Martin: There is a variation of the method given by Johnson and Jacoby which is more accurate, though more cumbersome, when applied to concrete arches. The moment of inertia of the arch rib can often be made to vary approximately as the square, or third or fourth power of the secant of the angle of inclination of the arch rib.

The equations produced by these conditions can be integrated and cleared, and possibly those of even higher powers, although I have never succeeded with the fifth power; however, I have never had time to try very hard with that power. Owing to lack of time I have not been able to arrange the formulae for these conditions for presentation in this discussion.

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*Chief Inspector, Modjeski & Angier, Inspecting Civil Engineers, Pittsburgh.

THE AUTHOR: Speaking of Professor Cain's method, dividing it in the ratio of the arch in the way you speak of, I had a letter from Professor Spofford, of Massachusetts Institute of Technology, giving a method that is practically the same as this of Muller-Breslau, and he finds fault with Professor Cain for the reason I mentioned in my paper, that the segments are pretty long in some cases and in some cases rather short. I am inclined to think that the increased length of the segments in the thicker and stiffer parts of the arch and shorter segments in the more flexible parts rather increase than diminish the accuracy of the result, but I have made no tests.

MR. JOHN A. FERGUSON:* In adapting graphical analysis to reinforced concrete arch designing, I have hit upon a combination of mathematical and graphical analysis that, while based upon methods of indirect or so-called approximate integration, is no more indirect or an approximation than any of the more commonly used approximations made for analytical solutions. This is, in effect, an application of Mr. Whited's method No. 3, and is based upon assumptions that will be briefly stated in order to present the problems in entirety.

The problem is presented in the form in which it was first worked out. This was for a reinforced concrete arch of considerable magnitude, and quite a high rise in proportion to the span, and the assumptions have all been made for the above case, though they may be modified so as to make the solution apply to an arch of any material by changing the assumptions and the form of of any material by changing the assumptions and certain details of the solution.

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*Secretary-Engineer, Building Code Commission, City of Pittsburgh, City Hall.

ASSUMPTIONS

1. The neutral axis is assumed to be at the center line of the rib all the way across the span. The moment arms must then be assumed to be the perpendicular distance from the thrust line to the center line of the arch.

This assumption introduces some error, but in this case its amount will be seen to be not large. The actual neutral axis of a reinforced beam, curved or rectilinear, is not at the center line. It is not as far from the center line in an arch or bent beam which is subject to combined longitudinal and bending strains as when subject to bending alone. The position of the neutral axis varies with the distribution of the live load, and the change in length of the arch from expansion and contraction due to temperature changes, assuming the case of fixed abutments. Knowing that the relative amount of live load and that of the dead load is usually very small, it is easy to see that the live load will not usually affect the position of the neutral axis in any great degree. Temperature changes affect the moments in a much larger degree, and this shows that the neutral axis is shifted about from side to side of the center line of the arch to a marked degree.

2. That the sum of all the forces and moments acting over an appreciable length of the arch axis will produce the same strains as the total of the forces acting about the point which is at the center of gravity of the arch section included within the length taken. This assumption becomes the more nearly true the shorter the section of arch included.

This is the usual assumption whenever any but the longest and most extended integrations are employed, and must be included in any solution, analytical or graphical, that has to do with panel length units.

Other than the above assumptions there are some approximations employed in this solution which may be best explained as they are encountered in the solution.

Following is a statement of conditions of equilibrium:

ANALYTICAL PORTION OF THE SOLUTION

The static condition that the arch will remain motionless vertically:

$$V_1 + V_2 = P \dots\dots\dots (I)$$

The static condition that the arch will remain motionless horizontally:

$$H_1 - H_2 = O \dots\dots\dots (II)$$

The static condition that rotation of the arch shall not occur:

$$P k l + Hy_1 - Hy_2 - V_2 l = O \dots\dots\dots (III)$$

The elastic condition that the arch is fixed at the ends so that the sum of the changes in the angle of inclination between the abutments is equal to zero:

$$\int_o^l \frac{Mds}{E I} = O \dots\dots\dots (IV)$$

The elastic condition that the sum of the moments of the horizontal components of the thrust lines is equal to zero:

$$\int_o^l \frac{My\,ds}{E I} = O \dots\dots\dots (V)$$

The elastic condition that the sum of the moments of the vertical components of the thrust lines is equal to zero:

$$\int_o^l \frac{Mxds}{E I} = O \dots\dots\dots (VI)$$

If we now consider that the integration of the equations is to take some form so that it may be performed upon the formulas before applying them to the solution of an actual case, it will be most simple to bring the equations into the usual parabolic form and find what corrections must be applied thereto in order to bring about a correct result.

If, then, we were to discover some arch whose axis follows the simple curve of the parabola, the analysis of which would result in the same calculated unit strains as would the complete solution of the actual arch under solution, then the problem may become very much simplified and the engineer's task that much less difficult and, at the same time, somewhat less liable to error.

Beginning then with the equation of a symmetrical parabolic arch rib, the equation of the axis with the origin at the left springing is:

$$y = \frac{4h}{l^2}(lx - x^2) \ldots\ldots\ldots\ldots \text{(a)}$$

The values of the moments on the left and right of the load at l are as follows, using vertical forces, referring to the upper portion of Fig. 21:

$$\text{Left } M_L' = V_1 x \ldots\ldots\ldots\ldots (1)$$

$$\text{Right } M_R' = V_1 x - P\,(x - kl) \ldots\ldots\ldots\ldots (2)$$

and using the horizontal forces:

$$M_L'' = -\,H_1\,(y - y_1) \ldots\ldots\ldots\ldots (3)$$

$$M_R'' = H_2\,(y - y_2) \ldots\ldots\ldots\ldots (4)$$

Knowing that

$$M = M' + M'' \ldots\ldots\ldots\ldots (5)$$

we may express the elastic conditions of equilibrium in the following forms:

$$\int_o^{kl} \frac{M'ds}{E\,I} + \int_{kl}^{l} \frac{M'ds}{EI} + \int_o^{l} \frac{M''ds}{E\,I} = O \ldots\ldots \text{(IVa)}$$

$$\int_o^{kl} \frac{M'yds}{E\,I} + \int_{kl}^{l} \frac{M'yds}{E\,I} + \int_o^{l} \frac{M''yds}{E\,I} = O \ldots\ldots \text{(Va)}$$

$$\int_o^{kl} \frac{M'xds}{E\,I} + \int_{kl}^{l} \frac{M'yds}{E\,I} + \int_o^{l} \frac{M''yds}{E\,I} = O \ldots \text{(VIa)}$$

Since it is a pretty difficult matter to integrate the above equations, it will be expedient to make some assumption that will put the equations in such a form that they will not contain the complex variable.

Since

$$ds = dx \sec \theta \ldots\ldots\ldots\ldots (6)$$

the equation may be put in the form

$$\int \frac{M' \sec \theta\, dx}{E\,I} = O$$

If we are to assume that

$$I_x = I_0 \sec \theta \ldots\ldots\ldots\ldots (7)$$

the equations take the general form

$$\frac{1}{E\,I}\int M'\,dx = O \quad \ldots\ldots (8)$$

which is a very simple form to integrate.

Since it is not possible from the very nature of the material to so proportion a reinforced concrete arch that equation (7) will be satisfied, the device employed by Professor Cain must be used. It is quite simply done by assuming that the arch will be so divided into panel lengths that

$$\frac{s}{E\ I} = a\ constant$$

when equations (IVa), (Va) and (VIa) will assume the form

$$\frac{1}{E\,I_0}\left\{\int_o^{kl} M'dx + \int_{kl}^{l} M'dx + \int_o^{l} M''dx\right\} = O \quad \ldots\ldots (IVb)$$

$$\frac{1}{E\,I_0}\left\{\int_n^{kl} M'ydx + \int_{kl}^{l} M'ydx + \int_o^{l} M''ydx\right\} = O \quad \ldots\ldots (Vb)$$

$$\frac{1}{E\,I_0}\left\{\int_o^{kl} M'xdx + \int_{kl}^{l} M'xdx + \int_o^{l} M''xdx\right\} = O \quad \ldots\ldots (VIb)$$

These equations are still of the general form, and any solution must be made by solving them after having found the equation of the arch axis. It is always very hard to perform the integrations of any of the regular curves besides the parabola. If any other curve might be found that would be easy to integrate and would still fit closely to the curve of equilibrium of forces, the solution could be made very simple indeed. I have, however, never been able to find any one equation which would fit all cases. Every one that I have so far been able to derive in any individual case has either been a very poor fit or else the integrals could not be found by any process except mechanical summation by panel points.

There is a very simple method, however, that may be applied as an approximation of the longer and more accurate one. There are two ways of being reasonably sure of accuracy sufficient for all purposes. One of these is to be sure the approximate methods will bear the light of careful study, and the other to check back by longhand methods a few times to see if there is a large discrep-

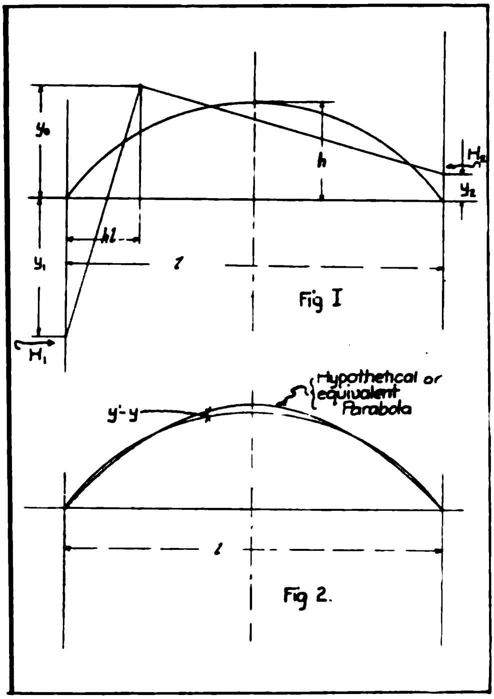

Fig. 21.

ancy of results. The following method has been subjected to both of the above:

If, then, knowing the simplicity of the integrals from the parabolic equations, it is possible to find a hypothetical arch which will have the same span, the same mass and general dimensions, which follows the parabolic curvature, and has the same strains when subjected to the same loading conditions (see lower portion of Fig. 21). It is only necessary to proceed with the solution in the usual manner and apply ratios such as will satisfy all conditions. Such an equation may be derived by going through the steps indicated below:

First, the statement must be made that the equations of equilibrium are equal to each other in the two arches, and then find what must be done in order to satisfy this equality in each of the six equations, letting the right-hand member with primes represent the conditions for the parabola.

$$V_1 + V_2 - P = V'_1 + V'_2 - P' \qquad \text{(Ic)}$$

$$H_1 - H_2 = H'_1 - H'_2 \qquad \text{(IIc)}$$

$$Pkl + Hy_1 - Hy_2 - V_2 l = P'kl + H'y'_1 - H'y'_2 - V'_2 l \qquad \text{(IIIc)}$$

$$\int_0^l \frac{Mds}{EI} = \int_0^l \frac{M'ds}{EI} \qquad \text{(IVc)}$$

$$\int_0^l \frac{Myds}{EI} = \int_0^l \frac{M'y'ds}{EI} \qquad \text{(Vc)}$$

$$\int_0^l \frac{Mxds}{EI} = \int_0^l \frac{M'xds}{EI} \qquad \text{(VIc)}$$

Let us introduce here the general equation of the symmetrical parabola with the origin at the left springing and passing through the same springing points with, however, not necessarily the same rise as that of the arch.

$$y = \frac{4h}{l^2}(lx - x^2)$$

Now, let us review equations (Ic) to (VIc). It will be seen that:

Equation (Ic) is satisfied, since the mass of the hypothetical arch is to be the same as that of the actual arch;

Equation (IIc) will be satisfied if:

$$Hy_1 = H'y'_1 \quad \text{and}$$
$$Hy_2 = H'y'_2$$

which means that the moments at the springing must be equal in the two arches. Knowing that the value of H must be different in the hypothetical arch from the value for the actual arch, it will be necessary to vary the values of y_1 and y_2 in order to satisfy the equality. A correction applied to the values of y_1 and y_2 will suffice to bring about the desired result.

Equation (IIIc) will be satisfied for the same reasons, and by the same correction the equality may be satisfied.

Equation (IVc), which may be expressed in the form of (IVb) if

$$\Sigma M = \Sigma M'$$

This may readily be proved later.

Equation (Vc), expressed in the form of (Vb), will be satisfied if

$$\Sigma\ y = \Sigma\ y'$$

It is possible to so choose the hypothetical parabola that this will be possible. The simple assumption must be made that the hypothetical parabolic arch will include between it and the springing line exactly the same area as is included between the actual arch axis and the springing line. The springing lines must be coincident. Also ΣM must equal $\Sigma M'$ in order to satisfy this equation.

Equation (VIc), expressed in the form (VIb), will be satisfied in the same manner as (IVc), since it is obvious the values of X will be the same in the hypothetical arch as in the actual.

An inspection of the lower portion of Fig. 21 and Fig. 22 will show that if the actual arch axis be so chosen that the equilibrium polygon lies halfway between the actual arch axis and that of the hypothetical arch axis, the desired result will be accomplished as the acting arms, summed up across the span, will be equal to zero in each case. If it is possible to choose the arch axis in such a manner that these last two conditions take place, and the same being done for the hypothetical parabolic arch, it will appear that, except for the individual panel point values of M the solution of the parabolic arch will have the same results as those of the actual arch. Individual correction at each panel point by correcting the rectilinear intersection locus of the parabola will cause the errors to almost disappear. The correction will be applied by drawing a new curved intersection locus through points found by laying off from the rectilinear intersection locus,

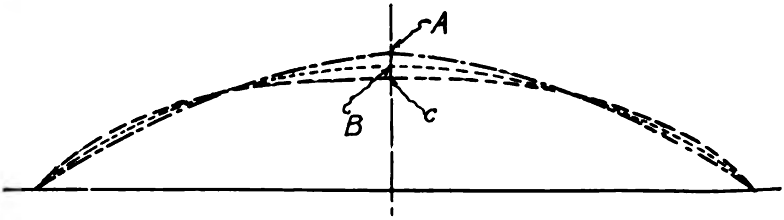

Fig. 22.
A = Hypothetical parabola. B = Equilibrium polygon.
C = Axis of actual arch.

ordinates equal to the vertical ordinate between the actual arch axis, and the hypothetical parabolic arch axis. These ordinates must be laid off in the opposite sense to the parabolic axis with respect to that of the actual axis. This will not be done as a correction to y_0, but simply as a corrective to the value of M.

The correction that must be made to the values of y_1 and y_2 and to y'_1 and y'_2, in order to cause equations (IIc) and (IIIc), may be found by the following:

Since $y_1 = \frac{H_1}{M_1}$

$$y'_1 = \frac{H'}{M'}$$

If $Y = \frac{\Sigma(y - ya)}{\Sigma y\,(y - ya)}$ and

$$Y' = \frac{\Sigma\ (y' - y'a)}{\Sigma y'\ (y' - y'a)}$$

then $\frac{H_1}{M_1} = y_1$

will bear the same ratio to

$$\frac{H'_1}{M'_1} = y'_1$$

that Y bears to Y'.

Hence the proportion

$$y_1 : y'_1 :: Y : Y'$$

or $y_1 = \frac{y'_1 Y}{Y'}$

Similarly $y_2 = \frac{y'_2 Y}{Y'}$

and even though

$$Mx = V_1 x$$

on the left of the load and

$$Mx = V_1 x - P(x - kl)$$

on the right, these quantities can be shown to cancel out each time.

The value of y_0 may be found in its correspondingly corrected form by the same manner of reasoning as the above by knowing that

$$\frac{y_0 - y_1}{kl} = \frac{V_1}{H_1}$$

from which

$$y_0 = \frac{V_1kl}{H_1} + y_1$$

from which by priming the same values for the case of the hypothetical arch, we have the following proportion:

$$y_0 : y'_0 :: \frac{V_1kl}{H_1} + y_1 : \frac{V_1kl}{H'_1} + y'_1$$

Since

$$\frac{V_1}{H_1} = \frac{kl}{y_0 - y_1}$$

which is also true for the parabola, we may find

$$\frac{y_0}{y'_0} = \frac{\frac{(kl)^2}{y_0 - y'_0} + y_1}{\frac{(kl)^2}{y_0 - y_1} + y'_1}$$

In the case of one bridge whose rise was relatively quite high compared to the span, the following values were found:

$$y_0 = 0.996\ y'_0$$
$$y_1 = 1.040\ y'_1$$
$$y_2 = 1.040\ y'_2$$

Having found such corrections, any one of the graphical solutions may be employed in the solution of the arch.

PROF. H. R. THAYER:* I am very much interested in Mr. Whited's excellent paper. This is particularly true with his description of the ellipse method. I would like very much to see an example worked out. Would the results differ materially from those obtained by the Muller-Breslau method?

The writer prefers the latter. In the first place, tests have shown that it is substantially correct. Next, the computations, while just a bit tedious, are not at all difficult once that the engineer has grasped the meaning of the different equations. And finally the formulas giving H and V in equation (6) can readily be solved by a graphical construction which is extremely simple.

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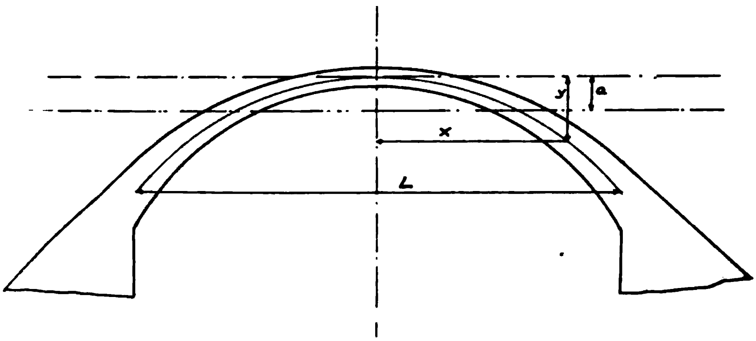

Fig. 23.

There is an allied question which is well worth serious study. That is to derive what I shall call an ideal equation for the center line of the arch. It should come very close to the curve of equilibrium under dead loads, and it must integrate in connection with some quantity expressing the depth into a simple algebraic function. If this were once done we could derive formulas for the reactions, shears and moments due to all sorts of loadings.

MR. N. F. HOPKINS:* Mr. Whited's paper seems to leave little to be said upon the general theory of the elastic arch. There are, however, various methods of applying the theory to practice.

If the vertical co-ordinates of the arch, and of the moment diagram, and the ratio of the secant of the angle of inclination of the arch to the moment of inertia, could all be expressed as exact functions of the span of the arch, or the horizontal co-ordinate, the method of combining their products and integrating would be exact.

As these functions do not always follow laws expressible in terms capable of integration, some method of approximation is necessary. The method by graphics has been a favorite with most writers. The following method is one based upon algebraical statements of the several functions of an arch followed by integration of their combinations.

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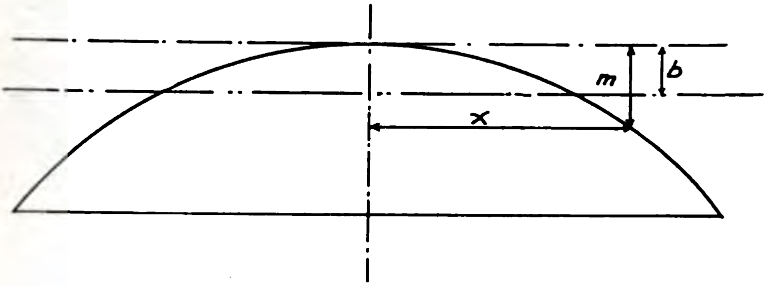

Fig. 24.

Let Fig. 23 represent a plain, spandrel filled concrete arch having a span of 100 ft., a rise of 20 ft. (of the neutral axis), a thickness at the crown of 2 ft., and at the springing line of 3.24 ft., the thickness at intermediate points varying so that a section of the arch one foot in length would have the following characteristics:

$$\frac{s}{I} = 1.5 - x^2$$

Where s is the secant of the angle of inclination of the neutral axis.

Where I is the moment of inertia of any section of the arch.

Where x is the distance from the center of the span to any point in terms of the half span, so that x at the mid-span is zero and at the springing line is unity.

Assume that the dead load on the arch is symmetrical, consists of the weight of the arch ring, backing and roadway, the unit load w varying so that

$$w = 600 + 1200x^2$$

Then if m is the difference between the moment at the crown and the moment at any other point, as shown in Fig. 24,—

$$m = \int_{x_1}^{\infty} \frac{L^2}{4} (x - x_1)\ (600 + 1200x_1^2) dx_1$$

$$= \int_{x_1}^{\infty} \frac{L^2}{4} (600x - 600xx_1 + 1200xx_1^2 - 1200x_1^3) dx_1$$

$$= \frac{L^2}{4} (600xx_1 - 300x_1^2 + 400xx_1^3 - 300x_1^4)$$

Calling $x_1 = x$ and assigning its value of 100 to L gives

$$m = 750\ 000\ x^2 + 250\ 000\ x^4$$

The curve of the neutral axis may be assumed such a curve that the vertical co-ordinate from the crown to any point may be expressed as:

$$y = 15x^2 + 5x^4$$

Having now expressions in algebraical form for the vertical co-ordinate of the arch, vertical co-ordinate of the moment diagram and of $s \div I$ proceed as follows:

$$\int_x^\infty \frac{s}{I} = 1.5x - \frac{x^3}{3}$$

$$\int_1^\infty \frac{s}{I} = 1.5 - 0.3333$$

$$= 1.1667$$

$$\frac{s}{I}\,y = 22.5x^2 - 7.5x^4 - 5x^6$$

$$\int_x^\infty \frac{s}{I}\,y = 7.5x^3 - 1.5x^5 - 0.7143\ x^7$$

$$\int_1^\infty \frac{s}{I}\,y = 7.5 - 1.5 - 0.7143$$

$$= 5.2857$$

$$\frac{\int_1^\infty \frac{s}{I}\,y}{\int_1^\infty \frac{s}{I}} = \frac{5.2857}{1.1667}$$

$$= 4.53$$

$$= a$$

Which gives the location of the point of contraflexure of the arch below the crown of the arch.

$$\frac{s}{I}\,y^2 = 337.5x^4 - 112.5x^8 - 25x^{10}$$

$$\int_x^\infty \frac{s}{I}\,y^2 = 67.5x^5 - 12.5x^9 - 2.273x^{11}$$

$$\int_1^\infty \frac{s}{I}\,y^2 = 67.5 - 12.5 - 2.273 = 52.727$$

$$a\int_1^\infty \frac{s}{I}\,y = 4.53 \times 5.2857 = 23.948$$

$$\int_1^\infty \frac{s}{I}\,y\,(y-a) = 28.779$$

Let A equal the area of a vertical section of the arch at any point. Then $1 \div A$ may be closely approximated by the formula

$$\frac{1}{A} = 0.5 - 0.19x^2$$

$$\int_x^0 \frac{1}{A} = 0.5x - 0.06x^2$$

$$\int_1^0 \frac{1}{A} = 0.5 - 0.06 = 00.44$$

$$\int_1^0 \frac{s}{I} y\ (y-a) = 28.78$$

$$\int_1^0 \frac{s}{I} y\ (y-a) + \int_1^0 \frac{1}{A} = 29.22$$

Let H_1 = the horizontal thrust due to temperature change

Let ϵ = the co-efficient of expansion due to temperature changes assumed to be 0.000006

Let E = the modulus of elasticity of concrete per square foot assumed 288 000 000.

Let t = change in Fahrenheit degrees

$$H_t = \frac{E\epsilon t}{\int_1^0 \frac{s}{I} y\ (y-a) + \int_1^0 \frac{1}{A}}$$

$$= \frac{-69\ 120}{29.22} = -2365, \text{ for } t = -40 \text{ deg.}$$

$$= \frac{34\ 560}{29.22} = 1182, \text{ for } t = 20 \text{ deg.}$$

for the dead load thrust.

$$\frac{s}{I} m = 1\ 125\ 000x^2 - 375\ 000\ x^4 - 250\ 000\ x^6$$

$$\int_x^0 \frac{s}{I} m = 375\ 000\ x^3 - 75\ 000\ x^5 - 35\ 714\ x^7$$

$$\int_1^0 \frac{s}{I} m = 375\ 000 - 75\ 000 - 35\ 714$$

$$= 264\ 286$$

$$\frac{\int_1^0 \frac{s}{I} m}{\int_1^0 \frac{s}{I}} = \frac{264\ 286}{1.1667} = 226\ 531$$

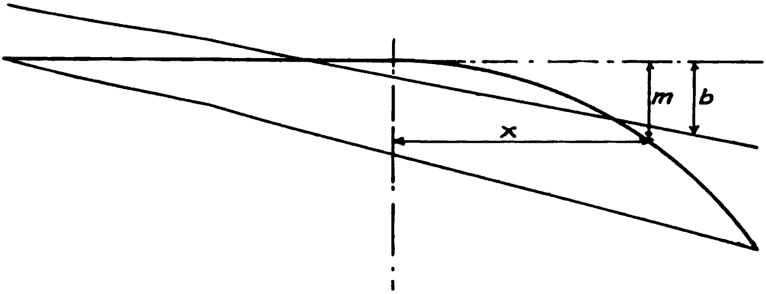

Fig. 25.

$$= b_0$$

$$\frac{s}{I}\,ym = 16\,875\,000x^4 - 5\,625\,000x^8 - 1\,250\,000x^{10}$$

$$\int_x^\infty \frac{s}{I}\,ym = 3\,375\,000x^5 - 625\,000x^9 - 113\,636x^{11}$$

$$\int_1^\infty \frac{s}{I}\,ym = 3\,375\,000 - 625\,000 - 113\,632 = 2\,636\,364$$

$$a\int_1^\infty \frac{s}{I}\,m = 4.53 \times 264\,286 = 1\,197\,374$$

$$\int_1^\infty \frac{s}{I}\,y\,(m-b) = 1\,438\,990$$

Assuming H to be the horizontal thrust,—

$$H = \frac{1\,438\,990}{29.22}$$

$$= 49\,247$$

A number of live loads may be assumed. For example, a live load of 100 lb. per sq. ft. on one-half the arch only, the moment diagram for which is shown in Fig. 25.

Where

$m = 125\,000\ x^2$ for the right half

$m = O$ for the left half

$$\frac{s}{I}\,m = 187\,500\ x^2 - 125\,000\ x^4$$

$$\int_x^\infty \frac{s}{I}\,m = 62\,500\ x^3 - 25\,000\ x^5$$

$$\int_1^\infty \frac{s}{I}\,m = 62\,500 - 25\,000$$

$$= 37\,500$$

$$\frac{\int_1^0 \frac{s}{I} m}{2\int_1^0 \frac{s}{I}} = \frac{37\,500}{2.333} = 16\,071$$

$$= b_0$$

$$\frac{s}{I} xm = 187\,500\ x^3 - 125\,000\ x^5$$

$$\int_x^0 \frac{s}{I}\ xm = 46\,875\ x^4 - 20\,833\ x^6$$

$$\int_1^0 \frac{s}{I}\ m = 46\,875 - 20\,833$$

$$= 26\,042$$

$$\frac{s}{I} x^2 = 1.5\ x^2 - x^4$$

$$\int_x^0 \frac{s}{I}\ x^2 = 0.5\ x^3 - 0.2\ x^5$$

$$\int_1^0 \frac{s}{I}\ xm = 0.5 - 0.2$$

$$= 0.3$$

$$2\int_1^0 \frac{s}{I}\ xm = 0.6$$

$$\frac{\int_1^0 \frac{s}{I}\ xm}{2\int_1^0 \frac{s}{I} x^2} = \frac{26\,042}{0.6} = 43\,403$$

Therefore

$$b = 16\,071 + 43\,043\ x$$

$$\frac{s}{I}\ my = 2\,812\,500\ x^4 - 937\,500\ x^6 - 625\,000\ x^8$$

$$\int_x^0 \frac{s}{I}\ my = 562\,500\ x^5 - 133\,929\ x^6 - 69\,222\ x^9$$

$$\int_1^0 \frac{s}{I}\ my = 562\,500 - 133\,929 - 69\,222$$

$$\int_1^0 \frac{s}{I}\ my = 359\,349$$

$$2a\int_1^0 \frac{}{I} = 164\,607$$

$$\overline{}$$

$$\int_1^{-1} \frac{s}{I}\ y(m-b) = 194\,742$$

Therefore

$$H_L = \frac{194\,742}{58.44}$$
$$= 3332$$

The accompanying tabulation gives the factors necessary in finding the fiber strain in the extrados and intrados (see pages 326 and 327):

A combination of the above fiber strains shows a maximum compressive fiber strain where the live load is on the half span at a fall in temperature of 40 deg., amounting to 58 423 lb. per sq. ft., or 406 lb. per sq. in.

The maximum tensile strain at a live load on half the span and a fall in temperature of 40 deg. amounts to 12 875 lb. per sq. ft., or 89 lb. per sq. in.

Both these maximum strains occur at springing line. The above arch is taken merely to show the method of calculation. In practice a multicentered arch approaching the above arch would likely be substituted therefor.

The writer does not think that the method advocated by Balet of calculating the strains in a parabola of equivalent area to a segmentalor three-centered arch would be advisable unless the ratio $s \div I$ is a constant for all points on the arch. The use of a parabola with a fractional exponent and of the same rise and area would be more advisable and nearly as easily handled, either graphically or algebraically, as a regular parabola.

The method advocated by Cain of dividing the arch into segments so that $s \div I$ is a constant (where s is a segment of the arch instead of as in the above discussion, the secant of the angle of inclination), while giving the horizontal thrust closely does not, in the writer's opinion, locate the relation between the moment diagram and the neutral axis at the springing line with sufficient accuracy.

Nearly all curves within the limits used in bridge work may be expressed as compound parabolas in the form,—

$y = ax^2 + bx^4 + cx^6 +$ etc., or

$y = ax^n$, where n may be a fractional exponent.

The moment of inertia can likewise be expressed in algebraical form approximately in most cases, as can also the moment diagram for the dead load, and the several live loads.

1 Horizontal Co-ord. x	2 Vertical Co-ord. y	3 $y-a$	4 θ	5 s $sec.\theta$	6 $sin.\theta$	7 $cos.\theta$	8 Depth of Rib p	9 Moment Inertia I	10 $\frac{s}{I}$	11 $\frac{6}{d^2}$
—1.0										
—0.8										
—0.6										
—0.4										
—0.2										
0	0	—4.530	0	1.000	0	1.0000	2.00	0.667	1.50	1.500
0.2	0.608	—3.922	7° 02′	1.008	0.1225	0.9925	2.02	0.690	1.46	1.464
0.4	2.528	—1.002	14° 53′	1.035	0.2568	0.9664	2.10	0.772	1.34	1.360
0.6	6.048	1.498	24° 04′	1.095	0.4078	0.9131	2.26	0.960	1.14	1.177
0.8	11.648	7.118	34° 20′	1.212	0.5640	0.8259	2.57	1.409	0.86	0.912
1.0	20.000	15.470	45° 00′	1.414	0.7071	0.7071	3.24	2.828	0.50	0.573

	Temperature Strains for —40°						Temp. Strains +20°	
1 Horizontal Co-ord. x	12 $M_t=H_t(y-a$	13 $\frac{6M_t}{d^2}$	14 Axial Thrust $T_t=H_t cos.\theta$	15 Fiber Strain $\frac{T_t}{p}$	16 Fiber Strains Extrados	17 Fiber Strains Intrados	18 Fiber Strains Extrados	19 Fiber Strains Intrados
—1.0								
—0.8								
—0.6								
—0.4								
—0.2								
0	10 713	16 070	—2 365	—1 182	14 888	—17 252	— 7 444	8 626
0.2	9 275	13 579	—2 347	—1 161	12 418	—14 740	— 6 209	7 370
0.4	2 370	3 223	—2 285	—1 088	2 135	— 4 311	— 1 067	2 156
0.6	— 3 543	— 4 170	—2 159	— 965	— 5 135	3 205	2 567	— 1 602
0.8	—16 834	—14 912	— 1 953	— 760	—15 702	14 182	7 861	— 7 091
1.0	—36 686	—20 964	—1 672	— 517	—21 481	20 447	10 740	10 223

1 Horizontal Co-ord.	20	21	22	23	24	25	26	27	28	29	30
										Fiber Strains	
x	$H(y-a)$	$(m-b)$	$M=H(y-a)-(m-b)$	$\frac{6M}{d^2}$	S_V = Vertical Shear	$S_V \sin.\theta$	$H \cos.\theta$	T = total dead load thrust	$\frac{T}{p}$	Extrados	Intrados
—1.0											
—0.8											
—0.6											
—0.4											
—0.2											
0	—223 088	—226 500	3 412	5 118	0	0	49 247	49 247	24 623	29 741	19 505
0.2	—193 147	—196 100	2 953	4 323	6 160	755	48 878	49 633	24 570	28 893	20 247
0.4	— 49 345	— 50 100	755	1 027	13 288	3 410	47 592	51 002	24 286	25 313	23 259
0.6	73 772	74 900	— 1 128	—1 328	23 120	9 428	44 967	54 395	24 068	22 740	25 396
0.8	350 540	355 900	— 5 359	—4 887	34 240	19 311	40 673	59 984	23 340	18 453	28 227
1.0	761 851	773 500	—11 649	—6 675	50 000	35 355	34 822	70 177	21 660	14 985	28 335

	Live Load on Half Span												
1 Horizontal Co-ord.	31	32	33	34	35	36	37	38	39	40	41	42	43
							Vertical Shear					Fiber Strains	
x	b	m	$(m-b)$	$H_L(y-a)$	M	$\frac{6M}{p^2}$	S_V	$S_V \sin.\theta$	$H_L \cos.\theta$	T	$\frac{T}{p}$	Extrados	Intrados
—1.0	—27 332	0	27 332	51 546	24 214	14 444	— 848	600	2 356	2 956	912	15 356	—13 532
—0.8	—18 651	0	18 651	23 717	5 066	4 620	— 848	478	2 752	3 230	1 256	5 876	— 3 365
—0.6	— 9 970	0	9 970	4 991	— 4 979	— 5 861	— 848	346	3 042	3 388	1 499	— 4 362	7 360
—0.4	— 1 290	0	1 290	— 3 339	— 4 629	— 6 295	— 848	218	3 220	3 438	1 637	— 4 658	7 932
—0.2	7 391	0	— 7 391	—13 068	— 5 677	— 8 311	— 848	104	3 307	3 411	1 688	— 6 623	9 999
0	16 071	0	—16 071	—15 094	977	1 466	— 848	0	3 332	3 332	1 666	3 132	200
0.2	24 752	5 000	—19 752	—13 068	6 688	9 791	142	17	3 307	3 324	1 645	11 436	— 8 146
0.4	33 432	20 000	—13 432	— 3 339	10 093	13 726	1 142	293	3 220	3 513	1 673	15 399	—12 053
0.6	42 113	45 000	2 887	4 991	2 104	2 476	2 142	674	3 042	3 716	1 644	4 120	— 832
0.8	50 793	80 000	29 207	23 717	— 5 490	— 5 007	3 142	1 772	2 752	4 524	1 760	— 3 247	6 767
1.0	59 474	125 000	65 526	51 546	—13 980	— 8 010	4 142	2 929	2 356	5 285	1 631	— 6 379	9 641

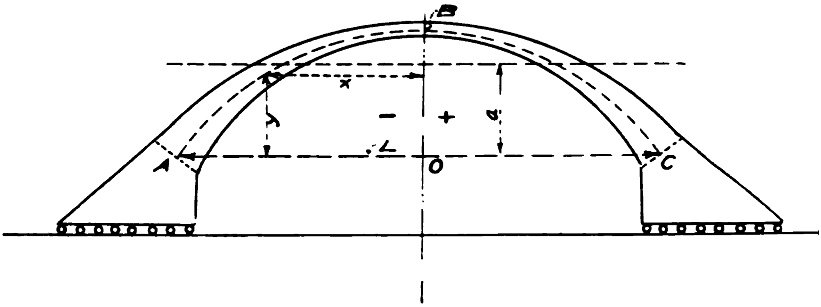

Fig. 26.

To show the derivation of the above formula the following theory has been used by the writer. It differs from Mr. Whited's analysis in the method of arriving at the conclusions, which are, however, the same.

Let *A, B, C* in Fig. 26 represent the neutral axis of a hingeless elastic arch rib of homogeneous materials, one foot wide, having a span *L* and length along neutral axis of *L'*. Suppose the arch to be without weight and resting on incompressible abutments, supported by frictionless rollers.

The effect of a load on the arch is similar to the effect of a load on a straight beam fixed at the ends, as the arch may be regarded as a curved beam. The thrust along the axis of the arch that would occur if the abutments were immovable moves the abutments along the rollers and increases the span of the arch from *L* to L_1, until the compressive strains in the arch are balanced by the tensile strains.

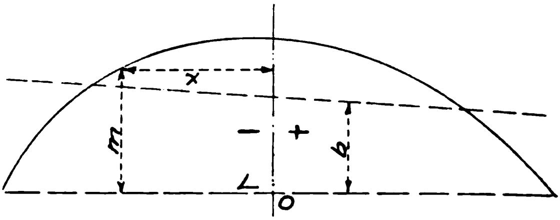

Fig. 27.

In a beam or arch fixed at the ends and having a variable cross section:

$$\Sigma \frac{s}{I} (m-b) = O \quad \text{.........................} (1)$$

$$\Sigma \frac{s}{I} x (m-b) = c \quad \text{.........................} (2)^*$$

where

s $=dL=$ the differential of the length of the neutral axis.

I $=$ the moment of inertia of any section.

m $=$ the static moment due to the loads at any point. See Fig. 27.

x $=$ the horizontal coordinate of the neutral axis from the center line of the span.

Σ $=$ the sign of summation, and in these formulae is for the length of the span.

$$b = \frac{\Sigma \frac{s}{I} m}{\Sigma \frac{s}{I}} + \frac{x \Sigma \frac{s}{I} m\, x}{\Sigma \frac{s}{I} x^2} - \frac{C}{\Sigma \frac{s}{I} x^2} \quad \text{..................} (3)$$

In an arch, or curved beam, the effect of positive bending moments is to increase the radius of curvature and, therefore, lengthen the span, and the effect of negative bending moments is to shorten the radius of curvature and therefore to shorten the length of span.

Fig. 28 represents a segment of an arch whose curvature has been changed. The effect of this change of curvature, if positive, is to shorten the extrados and lengthen the intrados by an amount

$$\frac{dL' f_c}{E}$$

and also to lengthen the span by an amount $d(L_1 - L)$ where f_c is the extreme fiber stress and E is the modulus of elasticity of the material.

Therefore, from similarity of triangles:

$$\frac{d\,(L_1 - L)}{y} = \frac{\frac{f_c}{E}}{\frac{p}{2}} dL'$$

---

*See Note 1 in Appendix for value of "c."

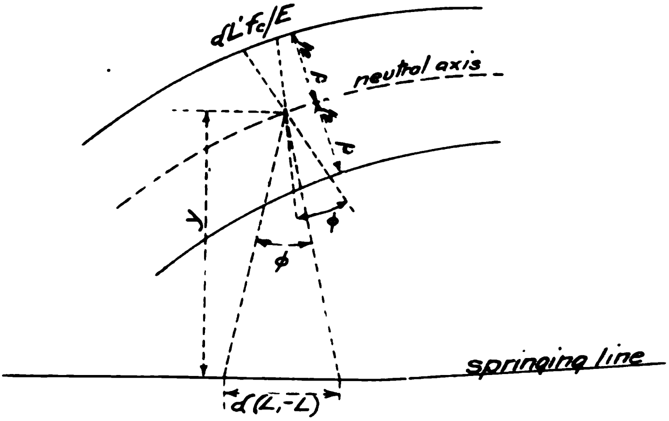

Fig. 28.

where y is the vertical co-ordinate from the springing line to the neutral axis and p is the depth of the arch rib. But

$$f_c = (m-b)\,\frac{6}{p^2}$$

therefore

$$\frac{d(L_1-L)}{y} = \frac{(m-b)12}{E\,p^3}\,d\,L' = \frac{m-b}{EI}\,s$$

$$d(L_1-L) = \frac{\frac{s}{I}\,y\,(m-b)}{E}$$

$$(L_1-L) = \frac{\Sigma\,\frac{s}{I}\,y(m-b)}{E} \quad \text{......................} (4)$$

This gives the lengthening of the span due to the loading of the arch. To shorten the length of span to the original length L requires the application of a horizontal force H to shove the abutments together the amount $(L_1 - L)$.

If the neutral axis is a straight line, as in a beam or column, a force H will shorten the span or length an amount:

$$(L_1-L) = \frac{\Sigma(dL)f_c}{E} = \frac{H\,\Sigma\,d\,L}{EA} \quad \text{..................} (5)$$

where

f_c = the fiber stress at any section.

A = the vertical area of any cross section.

Similarly, if the beam is curved to the form of an arch a force H will shorten the span an amount

$$(L_1-L_2) = \frac{H\,\Sigma\, d\,L}{EA} \qquad \text{(6)}$$

The neutral axis is not, however, a straight line, consequently the force H, in addition to the shortening $(L_1 - L_2)$ due to direct compression, also produces bending moments in the arch proportional to the deviation of the neutral axis from a line of a distance of a from the springing line of the arch. The distance of the neutral axis from this line is, therefore, $(y - a)$.

Referring again to Fig. 28 and substituting $(L_2 - L)$ for $(L_1 - L)$, from similarity of triangles:

$$\frac{d\,(L_2-L)}{y} = \frac{\frac{s}{I}\,H\,(y-a)}{E}$$

the factor $H\,(y - a)$ being the bending moment produced by the force H at a distance of $(y - a)$ from the neutral axis.

As the ends of the arch, or curved beam, are fixed

$$\Sigma\,\frac{s}{I}\,H\,(y-a) = O$$

$$\Sigma\,\frac{s}{I}\quad (y-a) = O$$

the factor H being a constant, therefore

$$a = \frac{\Sigma\,\frac{s}{I}\,y}{\Sigma\,\frac{s}{I}} \qquad \text{(7)}$$

$$d\,(L^2-L) = \frac{H\frac{s}{I}\,y\,(y-a)}{E}$$

$$(L_2-L) = \frac{H\,\Sigma\,\frac{s}{I}\,y\,(y-a)}{E} \qquad \text{(8)}$$

$$(L_1-L) = (L_2-L) + (L_1-L_2)$$

therefore

$$\frac{H\Sigma \frac{s}{I} y(y-a)}{E} + H\Sigma\frac{dL}{EA} = \frac{\Sigma\frac{s}{I}y(m-b)}{E}$$

$$H = \frac{\Sigma\frac{s}{I}y(m-b)}{\Sigma\frac{s}{I}y(y-a) + \Sigma\frac{dL}{A}} \quad\ldots\ldots(9)^*$$

This gives, therefore, the horizontal thrust due to the loads where the abutments are fixed. This formula, as is readily seen, provides for rib shortening.

Let M = the bending moment due to loads and thrust combined.
$= (m-b) - H(y-a)$
T = the axial thrust.
S_h = the normal shear.
$\phi = tan^{-1}\left(\frac{dy}{dx}\right)$
S_v = the vertical shear.

$$T = H\cos\theta + S_v\sin\theta \quad\ldots\ldots(11)$$

$$S_h = S_v\cos\theta - H\sin\theta \quad\ldots\ldots(12)$$

From the above it is apparent that

$$\Sigma\frac{Ms}{I} = O \quad\ldots\ldots(13)$$

and $\Sigma\frac{Mxs}{I} = O$ (see appendix) ……(14)

but $\Sigma\frac{Mys}{I} = H\Sigma\frac{dL}{A}$ ……(15)

Temperature changes, change the span of an arch similar to Fig. 26 an amount

$$(L_3-L) = L\epsilon t \quad\ldots\ldots(16)$$

Where ϵ = the coefficient of expansion.
t = degrees change in temperature.
Let H_t = the horizontal thrust required to shorten the span an amount $(L_3 - L)$.

---

*See Note 2 in Appendix.

Then from equations (6) and (8)

$$(L_3 - L) = H_t \left[\frac{\Sigma \frac{s}{I} y\,(y-a)}{E} + \Sigma \frac{d\,L}{EA} \right]$$

$$= L\epsilon t$$

$$t = \frac{E\,L\epsilon t}{\Sigma \frac{s}{I} y\,(y-a) + \Sigma \frac{dL}{A}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (17)$$

Let M_t = bending moment due to temperature.

$= H_t(y-a)$ .... (18)

T_t = axial thrust due to temperature.

$= H_t \cos\theta$ .... (19)

S_t = normal shear due to temperature.

$= H_t \sin\theta$ .... (20)

A change in temperature also changes the height of the arch an amount which we will designate as $(R_3 - R)$, where R is the normal rise of the arch. In an arch like Fig. 26, the increase in height would be.

$$(R_2 - R) = R\epsilon t \quad \ldots\ldots\ldots\ldots\ldots\ldots (21)$$

This is where the length of span is also changed proportionately due to the abutments moving along the rollers. If a force H_t then is applied to the abutments to change the span to the normal length L, the bending produced thereby also changes the rise an amount:

$$(R_3 - R_2) = \frac{H \int_{\frac{1}{2}L}^{\infty} \frac{s}{I}\, x\,(y-a)}{E}$$

$$(R_3 - R) = (R_3 - R_2) + (R_2 - R)$$

$$= \frac{H_t \int_{\frac{1}{2}L}^{\infty} \frac{s}{I}\, x\,(y-a)}{E + R\epsilon t} \quad \ldots\ldots\ldots\ldots\ldots\ldots (22)$$

This, therefore, gives the rise due to temperature for a hingeless elastic arch.

In a two-hinged arch the quantities a and b become zero.

Therefore

$$H = \frac{\Sigma \frac{s}{I} ym}{\Sigma \frac{s}{I} y^2 + \Sigma \frac{dL}{A}} \ldots\ldots (23)$$

$$M = m - Hy \ldots\ldots (24)$$

$$T = H \cos\theta + S_v \sin\theta \ldots\ldots (25)$$

$$S^h = S_v \cos\theta - H \sin\theta \ldots\ldots (26)$$

$$H_f = \frac{EL\epsilon t}{\Sigma \frac{s}{I} y^2 + \Sigma \frac{dL}{A}} \ldots\ldots (27)$$

$$(R_3 - R) = \frac{H_f \int_o^{\frac{1}{2}L} (\frac{1}{2}L - x)y}{E + R\epsilon t} \ldots\ldots (28)$$

In three-hinged arches the moment diagram must pass through three known points, therefore

$$H = \frac{m_0}{y_0} \ldots\ldots (29)$$

where m_0 and y_0 are the static moment and vertical co-ordinate, respectively, of the crown; M at the crown is therefore zero.

In Fig. 29 let $A\ C'\ B$ be the neutral axis of a hingeless elastic arch with a load W at C'.

$$H = \frac{\Sigma \frac{s}{I} y(m - b)}{\Sigma \frac{s}{I} y(y - a) + \Sigma \frac{(dL)}{A}}$$

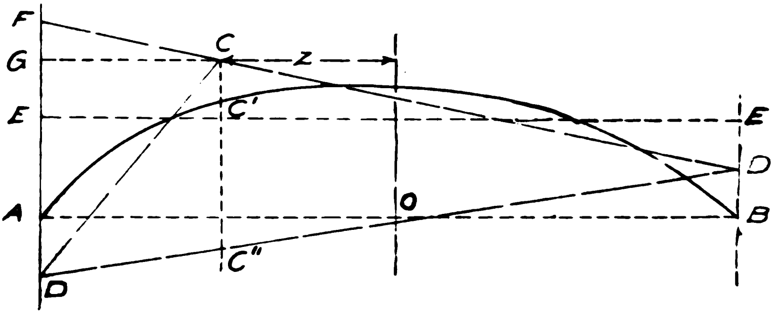

Fig. 29.

$$\Sigma\frac{s}{I}\,y(m-b) = \Sigma\frac{s}{I}\,my - \Sigma\frac{s}{I}\,yb$$

$$= \Sigma\frac{s}{I}\,my - \frac{\Sigma\frac{s}{I}y\,\Sigma\frac{s}{I}\,m}{\Sigma\frac{s}{I}} \quad \text{..........See (3)}$$

$$= \Sigma\frac{s}{I}\,my - a\Sigma\frac{s}{I}\,m \quad \text{................See (7)}$$

$$= \Sigma\frac{s}{I}\,m(y-a)$$

$$= \frac{W}{L}\left[\int_{\mathrm{C}}^{\mathrm{A}}(\tfrac{1}{2}L+Z)\ (\tfrac{1}{2}L-x)g + \int_{\mathrm{B}}^{\mathrm{C}}(\tfrac{1}{2}L-Z)\ (\tfrac{1}{2}L+x)g\right]$$

where $\frac{s}{I}(y-a) = g$

$$= \frac{W}{L}\left[\int_{\mathrm{C}}^{\mathrm{A}}g\frac{L^2}{4} - \int_{\mathrm{C}}^{\mathrm{A}}g\frac{Lx}{2} + \int_{\mathrm{C}}^{\mathrm{A}}g\frac{ZL}{2} - \int_{\mathrm{C}}^{\mathrm{A}}gZx + \int_{\mathrm{B}}^{\mathrm{C}}g\frac{L^2}{4} + \int_{\mathrm{B}}^{\mathrm{C}}g\frac{Lx}{2} - \int_{\mathrm{B}}^{\mathrm{C}}g\frac{ZL}{2} - \int_{\mathrm{B}}^{\mathrm{C}}gZx\right]$$

$$= \frac{W}{L}\left[\Sigma g\frac{L^2}{4} - L\int_{\mathrm{B}}^{\mathrm{A}}gx + ZL\int_{\mathrm{B}}^{\mathrm{A}}g - Z\Sigma gx\right]$$

$$= \frac{W}{L}\left[L\int_{\mathrm{B}}^{\mathrm{A}}(Z-x)g\right]$$

$$= W\int_{\mathrm{B}}^{\mathrm{A}}\frac{s}{I}\,(Z-x)\ (y-a)$$

therefore

$$H = \frac{W\int_{\frac{1}{2}\mathrm{L}}^{\mathrm{Z}}\frac{s}{I}(Z-x)\ (y-a)}{\Sigma\frac{s}{I}\,y(y-a) + \Sigma\,\frac{dL}{A}} \quad \text{................(30)}$$

$$M_0 = (m_0-b_0) - H(y-a)$$

$=$ moment at center of span.

$$m_0 = \frac{\left(\frac{L}{2}-Z\right)\frac{LW}{2}}{L}$$

$$= \frac{\left(\frac{L}{2} - Z\right) W}{2}$$

$$b_0 = \frac{\Sigma \frac{s}{I} m}{\Sigma \frac{s}{I}}$$

$$\Sigma \frac{s}{I} m = \int_{C}^{A} \frac{s}{I} (\tfrac{1}{2}L - x)(\tfrac{1}{2}L + Z)\frac{W}{L} + \int_{B}^{C} \frac{s}{I} (\tfrac{1}{2}L - Z)(\tfrac{1}{2}L + X)\frac{W}{L}$$

$$= \frac{W}{L}\left[\int_{C}^{A} \frac{s}{I}\,\frac{L^2}{4} + \int_{C}^{A} \frac{s}{I}\,\frac{LZ}{2} - \int_{C}^{A} \frac{s}{I}\,\frac{Lx}{2} - \int_{C}^{A} \frac{s}{I} ZX + \int_{B}^{C} \frac{s}{I}\,\frac{L^2}{4} - \int_{B}^{C} \frac{s}{I}\,\frac{LZ}{2} + \int_{B}^{C} \frac{s}{I}\,\frac{Lx}{2} - \int_{B}^{C} \frac{s}{I} ZX\right]$$

$$= \frac{W}{L}\left(\frac{L^2}{4}\Sigma \frac{s}{I} - \frac{Lz}{2}\Sigma \frac{s}{I} + L\int_{C}^{A} \frac{s}{I} z + \frac{L}{2}\Sigma \frac{s}{I} x - L\int_{C}^{A} \frac{s}{I} x - \Sigma \frac{s}{I} zx\right)$$

therefore

$$\frac{\Sigma \frac{s}{I} m}{\Sigma \frac{s}{I}} = \frac{W}{2}(\tfrac{1}{2}L - Z) - \frac{W \int_{C}^{A} \frac{s}{I}(x - Z)}{\Sigma \frac{s}{I}}$$

$$(m_0 - b_0) = \frac{W}{2}(\tfrac{1}{2}L - Z) - \frac{W}{2}(\tfrac{1}{2}L - Z) + \frac{W \int_{C}^{A} \frac{s}{I}(x - Z)}{\Sigma \frac{s}{I}}$$

$$M_0 = \frac{W \int_{\frac{1}{2}L}^{Z} \frac{s}{I}(x - Z)}{\Sigma \frac{s}{I}} - H(y - a) \ldots\ldots\ldots\ldots (31)$$

In Fig. 29 let

$$\frac{GD}{\tfrac{1}{2}L - Z} = \text{left reaction or shear.}$$

$$\frac{FG}{\frac{1}{2}L-Z}=\text{right reaction or shear.}$$
$$=S_0$$

$$\frac{F\ D}{\frac{L}{2}-Z}=W=\text{load at }C.$$

$$G\ D=CC''+\frac{\left(\frac{L}{2}-Z\right)\Sigma\frac{s}{I}\ m\ x}{\Sigma\frac{s}{I}\ x^2}\ \ldots\ldots\ldots\ldots\text{See}(3)$$

$$=\left(\frac{L}{2}-Z\right)\left(\frac{L}{2}-Z\right)\frac{W}{L}+\frac{\left(\frac{L}{2}-Z\right)\Sigma\frac{s}{I}\ m\ x}{\Sigma\frac{s}{I}\ x^2}$$

$$\frac{G\ D}{\frac{L}{2}-Z}=\left(\frac{L}{2}+Z\right)\frac{W}{L}+\frac{\Sigma\frac{s}{I}\ m\ x}{\Sigma\frac{s}{I}x^2}$$

$$\Sigma\frac{s}{I}m\ x=\frac{W}{L}\Big[\int_{\mathrm{C}}^{\mathrm{A}}\frac{s}{I}\left(\frac{L}{2}-\ x\right)\left(\frac{L}{2}+Z\right)x\ +\int_{\mathrm{B}}^{\mathrm{C}}\frac{s}{I}$$
$$\left(\frac{L}{2}+\ x\right)\left(\frac{L}{2}-\ Z\right)x\Big]$$

$$=\frac{W}{L}\Big[\int_{\mathrm{C}}^{\mathrm{A}}\frac{s}{I}\ \frac{L^2}{4}x\ +\int_{\mathrm{C}}^{\mathrm{A}}\frac{s}{I}\ \frac{Lz}{2}x\ -\int_{\mathrm{C}}^{\mathrm{A}}\frac{s}{I}$$
$$\frac{L}{2}\ x^2-\int_{\mathrm{C}}^{\mathrm{A}}\frac{s}{I}z\,x^2+\int_{\mathrm{B}}^{\mathrm{C}}\frac{s}{I}\ \frac{L^2}{4}\ x-\int_{\mathrm{B}}^{\mathrm{C}}\frac{s}{I}\ \frac{Lz}{2}x\ +$$
$$\int_{\mathrm{B}}^{\mathrm{C}}\frac{s}{I}\ \frac{L}{2}\ x^2-\int_{\mathrm{B}}^{\mathrm{C}}\frac{s}{I}z\,x^2\Big]$$

$$=\frac{W}{L}\Big[\frac{L^2}{4}\Sigma\frac{s}{I}x\ -\frac{Lz}{2}\Sigma\frac{s}{I}\ x+L\int_{\mathrm{C}}^{\mathrm{A}}\frac{s}{I}zx\ +\frac{L}{2}$$
$$\Sigma\frac{s}{I}\ x^2-L\int_{\mathrm{C}}^{\mathrm{A}}\frac{s}{I}\times^2-z\ \Sigma\frac{s}{I}x^2\Big]$$

$$=\frac{L}{W}\Big[\ \frac{L}{2}\Sigma\frac{s}{I}\ \ x^2—Z\Sigma\frac{s}{I}x^2—L\int_{\mathrm{C}}^{\mathrm{A}}\frac{s}{I}(x—z)x\ \Big]$$

$$\frac{\Sigma\frac{s}{I}mx}{\Sigma\frac{s}{I}\ x^2}=\frac{W}{L}\ \frac{\frac{1}{2}L-Z-L\int_{\mathrm{C}}^{\mathrm{A}}\frac{s}{I}(x-Z)x}{\Sigma\frac{s}{I}x^2}$$

$$\frac{GD}{(\tfrac{1}{2}L-Z)}=W-\frac{W\int_{\mathrm{C}}^{\mathrm{A}}\frac{s}{I}(x-z)x}{\Sigma\frac{s}{I}x^2}$$

$$S_0=\frac{W\int_{\frac{1}{2}\mathrm{L}}^{\mathrm{Z}}\frac{s}{I}(x-Z)x}{\Sigma\frac{s}{I}x^2}\quad\ldots\ldots\ldots\ldots(32)$$

For a number of loads

$$H=\frac{\Sigma W\int_{\frac{1}{2}\mathrm{L}}^{\mathrm{Z}}\frac{s}{I}(Z-x)(y-a)}{\Sigma\frac{s}{I}y(y-a)+\frac{\Sigma(dL)}{A}}$$

Let $\frac{s}{I}(y-a)=g$

$$\therefore\Sigma W\int_{\frac{1}{2}\mathrm{L}}^{\mathrm{Z}}(z-x)\frac{s}{I}(y-a)=\Sigma W\int_{\frac{1}{2}\mathrm{L}}^{\mathrm{Z}}zg-\Sigma W\int_{\frac{1}{2}\mathrm{L}}^{\mathrm{Z}}xg$$

$$\begin{aligned}\Sigma W\int_{\frac{1}{2}\mathrm{L}}^{\mathrm{Z}}zg=W_1Z_1\int_{\mathrm{Z}_2}^{\mathrm{Z}_1}g+W_1Z_1\int_{\mathrm{Z}_3}^{\mathrm{Z}_2}g+W_1Z_1\int_{\mathrm{Z}_4}^{\mathrm{Z}_3}g&+\text{etc.}\\+W_2Z_2\int_{\mathrm{Z}_3}^{\mathrm{Z}_2}g+W_2Z_2\int_{\mathrm{Z}_4}^{\mathrm{Z}_3}g&+\text{etc.}\\+W_3Z_3\int_{\mathrm{Z}_4}^{\mathrm{Z}_3}g&+\text{etc.}\end{aligned}$$

$$=\Sigma\left(\int_{Z}^{o}WZ\right)\left(\int_{Z,}^{Z}g\right)$$

Similarly

$$\Sigma W\int_{\frac{1}{2}\mathrm{L}}^{\mathrm{Z}}xg=\int_{\mathrm{Z}}^{o}W\int_{\mathrm{Z}'}^{\mathrm{Z}}xg$$

$$H=\frac{\Sigma\int_{\mathrm{Z}}^{o}WZ\int_{\mathrm{Z}'}^{\mathrm{Z}}\frac{s}{I}(y-a)-\Sigma\int_{\mathrm{Z}}^{o}W\int_{\mathrm{Z}'}^{\mathrm{Z}}\frac{s}{I}x(y-a)}{\Sigma\frac{s}{I}y(y-a)+\Sigma\frac{dL}{A}}\quad\ldots\ldots(33)$$

$$M_0=\frac{\Sigma\int_{\mathrm{Z}}^{o}W\int_{\mathrm{Z}'}^{\mathrm{Z}}\frac{s}{I}x-\Sigma\int_{\mathrm{Z}}^{o}ZW\int_{\mathrm{Z}'}^{\mathrm{Z}}\frac{s}{I}}{\Sigma\frac{s}{I}-H(y-a)}\quad\ldots\ldots\ldots\ldots\ldots(34)$$

$$S_0=\frac{\Sigma\int_z^o W\int_{z'}^{z}\frac{s}{I}x^2-\Sigma\int_z^o ZW\int_{z'}^{z}\frac{s}{I}x}{\Sigma\frac{s}{I}x^2}\ \ldots\ldots\ldots\ldots\ (35)$$

The moment M at any point by reference to Fig. 29 is

$$M=M_0+\frac{x}{\frac{1}{2}L-Z}S_0\left(\tfrac{1}{2}L-Z\right)-\int_x^o\frac{x-Z}{\frac{1}{2}L-Z}W(\tfrac{1}{2}L-Z)+H(Y_0-y)$$

$$=M_0+xS_0-\int_x^o(x-Z)W+H(y_0-y)\ldots\ldots\ldots\ldots(36)$$

$$S_v=S_0-\int_x^o W\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(37)$$

= the vertical shear.

The normal shear and axial thrust may be calculated by equations (10) and (12).

In the above formulae s has been taken as a differential of L. It may, however, be taken as a considerable segment of the arch, and in that case I may be taken at the middle point of the segment, as an average of the whole segment.

To facilitate the calculations, it is convenient to so select the lengths of s that $s \div I$ is a constant.

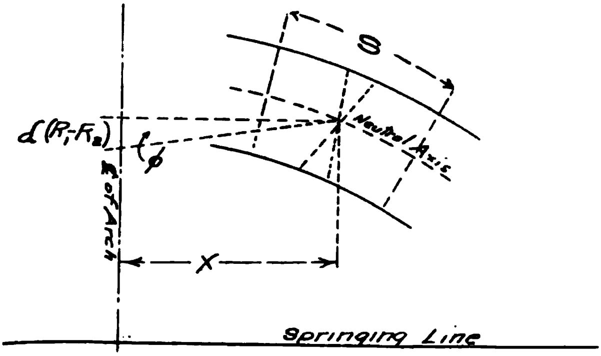

Fig. 30.

APPENDIX

Note No. 1—To find value of c:

Let Fig. 30 represent a segment of an arch subject to a bending strain and also subject to compression by reason of a force S_v the vertical shear. Hence the shortening in the rise due to the vertical shear is

$$d(R-R_1)=\frac{S_v dR}{EA'}$$

R = the normal rise of the arch

dR = differential of the rise

A' = the area of a horizontal section of the arch of the middle of the segment S

The shortening in the rise of the arch due to the change in curvature in the segment S would be

$$d(R_1-R_2)=-\phi x$$

Where ϕ is the total angular deflection in the segment supposed to be concentrated at the middle point of the segment.

but

$$\phi=\frac{Ms}{EI}$$

and

$$d(R_1-R_2)=-\frac{Mxs}{EI}$$

The total change in the rise of the arch due to the distortion of S is, therefore:

$$\begin{aligned}
d(R-R_1)+d(R_1-R_2) &= d(R-R_2)\\
&= \frac{-Mxs}{EI}+\frac{S_v dR}{EA'}\\
R-R_2 &= -\int_{\frac{1}{2}L}^{o}\frac{Mxs}{EI}+\int_{\frac{1}{2}L}^{o}\frac{S_v dR}{EA'}\\
&= \int_{\frac{1}{2}L}^{o}\frac{Mxs}{EI}-\int_{\frac{1}{2}L}^{o}\frac{S_v dR}{EA'}\\
\frac{\Sigma Mxs}{EI} &= \frac{\Sigma S_v dR}{EA'}
\end{aligned}$$

Let

$$M=(m-b)$$

and assume E constant

$$\Sigma\frac{s}{I}x(m-b)=\Sigma\ \frac{S_t dR}{A'}$$

$$=c$$

In practice the assumption may be made:

$$c=O$$

Note No. 2:

The formula

$$H=\frac{\Sigma\frac{s}{I}y(m-b)}{\Sigma\frac{s}{I}y(y-a)+\ \Sigma\frac{dL}{A}}\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (9)$$

may be written in the form

$$H=\alpha-\alpha\beta+\alpha\beta^2-\alpha\beta^3+\alpha\beta^4 \text{ etc } \ldots\ldots\ldots\ldots\ldots\ldots\ (9\text{-A})$$

where

$$\alpha=\frac{\Sigma\frac{s}{I}y(m-b)}{\Sigma\frac{s}{I}y(y-a)}$$

$$\beta=\frac{\Sigma d\frac{L}{A}}{\Sigma\frac{s}{I}y(y-a)}$$

Excepting in very flat arches, only the first two terms in the right hand member of the formula (9-A) need be used. $\alpha\beta$ is then known as the rib shortening thrust.

PROF. C. M. SPOFFORD:* Mr. Whited's paper is an excellent presentation of certain mathematical formulas relating to elastic hingeless arches and is worthy of careful study. It has been the writer's experience that simple numerical problems showing the application of equations, even those of the simplest form, are highly desirable in assisting the average reader to comprehend fully the methods involved, and it is to be hoped that Mr. Whited will be able to present such examples in the closure of his paper.

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The author has done wisely in calling attention to the value of approximate methods of integration, such as the application of Simpson's rule, as a method for solving definite integrals of the first order involving but one integral, since the application of such methods of integration to engineering structures is sufficiently accurate in nearly all cases and permits the solution of what would otherwise be impracticable integrals.

Equations 1-22, inclusive, as developed by Mr. Whited, are all based on the method of deflections. The development of the well-known fundamental formulas derived by this method, viz.,

$$\int\frac{Myds}{EI}, \int\frac{Mxds}{EI}, \text{ and} \int\frac{Mds}{EI}$$

is not included in the paper, presumably because this is given in such well-known standard text books as *Mechanics of Engineering,* Church; *Modern Framed Structures,* Part 2, Johnson, Bryan and Turneaure; *A Treatise on Arches,* Howe.

The writer has derived, by the Method of Least Work, simple formulas for symmetrical hingeless arches referred to the same axes as those used by Mr. Whited in the development of formulas 1 to 22, and would refer the reader who may be interested to the second edition of his book, *The Theory of Structures,* in which the treatment is given in full. He considers this method somewhat simpler than the method of deflection used by Mr. Whited.

It is always interesting and advisable to test engineering formulas by applying them to a simple case, the solution of which is obvious, or which may be obtained by other formulas. This may be done for arch formulas, such as Mr. Whited has given, by applying them to the extreme case of an arch with an infinite radius which corresponds to a fixed-ended beam, and comparing the results with those which would be obtained by the ordinary formulas for fixed-ended beams. The writer has done this in the case of the formulas just mentioned and has found that the same results were obtained by both sets of formulas. He has no doubt that the formulas presented by Mr. Whited would give similar results and hopes that Mr. Whited will publish such a comparison in his closure.

MR. WILLIS WHITED:* Regarding Prof. Spofford's remarks, I would say that the method of deflections is usually better understood by engineers than the principle of least work, the former being given very generally by writers on the elasticity of materials, while a number of fairly extensive treatises on elasticity of materials make no mention of the latter theory. To test a theory of the arch by applying it to a straight beam is very ingenious, but not always conclusive.

The writer was much interested in Mr. Ferguson's discussion and considers it quite valuable. Somewhat along the same line he would suggest that the following method could be applied to any ordinary arch and give results considerably more accurate than those given by equations (22):

Instead of assuming that

$$\frac{dS}{I} = \frac{dx}{I_0}$$

assume that

$$\frac{dS}{I} = \frac{dx}{I_0(1+ax)\sec\phi} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (A)$$

and if the curve differed considerably from a parabola, an equation of the form

$$y = bx^2 + cx^3 + dx^4 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (B)$$

could be determined which would correspond more closely to the actual form of the arch. These values, substituted in (19) and (20) could be integrated without great difficulty, (*A*) would probably be more useful than (*B*). Instead of (*A*) the form

$$\frac{dS}{I} = \frac{dx}{I_0 \sec\phi\,(1+ax+a'x^2)} \quad \ldots\ldots\ldots\ldots\ldots\ldots (C)$$

could be used, but the integration would be rather difficult unless the expression

$$1 + ax + a'x^2$$

could be readily factored.

The form shown in (*B*) is tangent to the axis of X at the origin. This method could be applied to a symmetrical arch by integrating the two sides separately. It is rather laborious, but a few values of the reactions could be determined by it as a check. In many cases d might be omitted.

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*Author's closure.

Owing to the pressure of other work, the author has not been able to work out an example to illustrate the application of the ellipse of elasticity.

I am very much gratified by the discussion which this paper has received, especially as it has brought out so many valuable points.

THE UTILIZATION OF BY-PRODUCTS FROM THE MANUFACTURE OF COKE

By C. G. ATWATER*

At a recent meeting of the American Chemical Society in New York for the award of the medal established in honor of Sir Henry Perkin (himself one of the greatest investigators in the field of coal by-products) to Dr. Leo Baekeland, a distinguished worker in the same fertile field, one of the speakers, referring to the coal tar chemical industry, said that it was not so much the relatively few millions of investment, but that with its hundreds of typical reactions, its thousands of substances, and its profound study of the actual spacial relation of atoms in the molecule, scientifically its development represented one of the greatest intellectual achievements of the race. It seems to me that this statement can be well made to cover the whole branch of coal by-products. I know of no substance whose uses so fill the scope of our engineering, manufacturing, chemical, domestic and social needs as do those of coal. Its consumption per capita is fairly taken as the measure of a nation's civilization; its possession is the guarantee of a nation's future; in the development of its possibilities we appear to have only crossed the threshold; in the application of the possibilities we have demonstrated, we are certainly far behind what might be done. While it is probably presumptuous for an outsider to attempt to tell the dwellers of the "Coal City" anything about coal that they do not already know, there may perhaps be some justification on the score that from a more distant point of view things may be seen less accurately but more nearly in their proper general proportions; and furthermore, that in the case of those who have no coal, the appreciation of its value is not dulled by possession.

If there be any one who doubts that great natural law of the indestructibility of matter, certainly consideration of coal and its by-products should convince him. We do not know how hot the sun was in the forests of the Coal Age; we do not know whether continuous thunder storms helped in nitrogen fixation; we do not know the color of the tropical vegetation, the odor of its blossoms, nor the taste of its fruits; whether they were poisonous or healthful, whether they grew slowly year by year or shot up over night as in fairy tales; but we do know that, buried deep in the earth, lost forever according to human standards, through centuries, we receive again the sun's heat and light and through the glowing furnace and in response to the chemist's skill we again see those colors, smell the odors, and grow sick or recover from the drugs. We may even taste those flavors and eat the fruits, or if not exactly them, at least some synthetic product so much like them that the ordinary man cannot tell the difference.

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Thirty-five years ago Sir William Siemens, a man of prophetic vision, speaking of the prospects he saw in the economical treatment of coal said: "I am bold enough to say that raw coal should not be used as fuel for any purpose whatsoever, and that the first step toward the judicious and economic production of heat is the gas-retort or gas-producer, in which coal is converted either entirely into gas, or into gas and coke, as is the case at our ordinary gas works." After thirty-five years we have made some progress and it seems now as though his vision were on the way to be fulfilled.

The distillation of coal is practiced in three general types of apparatus, namely, the coal gas retort, the bee-hive coke oven, and the by-product coke oven; therefore, the industries dealing with the products of coal distillation are based on the operation of these three agencies. The coal gas retort produces primarily coal gas for use as an illuminating gas and also as by-products, coke, tar and ammonia, and in some instances benzol and cyanides. The by-product coke oven produces coke as its main product and as by-products, gas, which may be used for illumination, tar, ammonia, benzol and cyanides. The beehive oven produces only coke and should not perhaps be included in this catalogue except that it comes under the general classification and is of interest as occupying the industrial field, which we may reasonably expect will ultimately be preempted by the by-product coke oven. It is, as it were, a measure of our immediate possibilities. I do not include the gas producer in this category because coal is not, strictly speaking, distilled destructively in this process, as air enough is introduced to partly consume it and transform it into carbonic oxid, which is attended with practically the destruction of the by-products of distillation except in the case of the recovery gas producers, where ammonia and a small amount of tar are recovered.

The development of the industries based upon the distillation of coal may be said in this country to have actually depended upon the introduction of the by-product coke oven. This statement will, I think, be justified by an examination of the conditions. It would not be true of Great Britain, to any such extent at least. The great extent to which coal gas is manufactured in England, and has been for many years, had supplied the raw materials for the chemical industries to work with, aided by the limited territory, which facilitates the assembling of supplies from different works.

This statement would be, however, true of Germany, where coal gas is not so widely used and where the introduction of the by-product coke oven began at an earlier date. In the United States the coal gas industry has long been in existence, but has been, as it were, diluted so much by the immense area of our country and the preponderance of carburetted water gas that until the advent of the by-product coke oven the supplies of raw material did not encourage the development of an extensive industry based on the products of coal.

In order to arrive at the relative importance of these three methods of destructive distillation, I would give the following figures, calculated from the latest reports of the United States Geological Survey:

	Tons	%
Coal distilled in by-product coke ovens	17 100 000	23
Coal distilled in coal gas retorts	4 000 000	6
Coal distilled in beehive coke ovens	52 100 000	71
Total coal distilled	73 200 000	

As will be seen from these figures, the by-product coke oven is about four times as great as the coal gas retort, but both combined fall far short of the total of the beehive coke oven. These figures indicate that a large amount of by-products are recovered. They also show that a still larger amount will ultimately be available and must be reckoned with in our industrial calculations.

The primary products of the distillation of coal, as I have already stated, are coke, gas, tar, ammonia, benzol and cyanides. To simplify matters I will take them up in order.

COKE

The nature and varieties of coke are, I presume, well known to you. Its main use is, of course, in the smelting of pig iron, for which approximately a ton must be manufactured for each ton of pig iron produced, although the actual consumption at the furnace is a little below this amount. For this purpose metallurgical coke is required, that is to say, coke having a strong cellular structure and reasonably low in sulphur, phosphorus and ash. Metallurgical coke is also used for remelting pig iron in the foundry cupola.

The softer coke produced by the coal gas retort has found ready consumption for ordinary fuel purposes. Aside from its lack of strength and liability to make breeze, it is better fitted for ordinary fuel purposes than the harder metallurgical coke, as it is not so difficult to ignite.

A considerable trade is being built up in certain districts in domestic coke, which is usually the by-product article crushed and sized and distributed in the usual manner. It has been found very satisfactory for all fuel purposes where a little attention is given to its properties, as distinct from authracite or bituminous coal. It is quite probable that the future will see considerable extension in this direction as the other products of coal distillation become more desired and justify investment in coking plants. In this connection it may be remarked that we are informed that large quantities of coke are now consumed in Germany in place of coal, it being desirable to operate their by-product coke ovens for the production of ammonia and of benzol, toluol, etc., although the coke is not specially required.

AMMONIA.

The usual way of obtaining ammonia in the by-product coke oven system has until recently been by washing the gas with water, which having a strong affinity for ammonia, absorbed it, the product being weak ammonia liquor. This ammonia liquor was distilled by steam in a column to form crude concentrated liquor or led into the sulphuric acid saturator, where by combination with sulphuric acid, sulphate of ammonia was formed. The sulphate was then dipped out of the saturating vessel, either by hand power or by air lift, dried in a centrifugal dryer and stored for shipping as the finished sulphate. Recent improvements in coke oven by-product apparatus have modified this method to the extent that the coke oven gas, after being freed from tar, is led directly to the saturating boxes and by the combination of the ammonia gas with the sulphuric acid, sulphate of ammonia is formed directly without the intervention of any washing water. This is known as the semi-direct process and produces an excellent quality of ammonia sulphate. In the plants that are so far in operation in this country, as those at Joliet, Gary and elsewhere, where ovens of the Koppers type are used, a certain amount of weak ammonia liquor is also produced, due to the cooling of the gas before passing through the saturator in order to remove the tar. With the tar a certain amount of ammonia liquor comes down. This ammonia liquor is usually in the form of the fixed salts—chloride, sulphate, sulphite, thiosulphate and ferrocyanide, and must be freed by the addition of lime or other alkali and distilled in the usual column still. The ammonia vapor so obtained is either returned to the gas main at a point just before the gas enters the ammonia saturator, or it can be kept apart and used for making ammonia liquor.

These two products, crude concentrated ammonia liquor and ammonium sulphate, are the primary ammonia products. From them the secondary products are manufactured. These comprise principally anhydrous ammonia and aqua ammonia, which are used in refrigeration and chemical manufacture; ammonium carbonate and ammonium bi-carbonate, which are used as leavening agents in baking; ammonium nitrate, which is used in the manufacture of explosives; ammonium chloride, more generally known as sal ammoniac, which is largely used in the manufacture of electric batteries and for various technical purposes. The most important of the products, as far as quantity goes, is ammonium sulphate. This is an important carrier of nitrogen for agricultural use and is a component of most mixed fertilizers produced in this country. It is generally accepted as one of the principal forms of nitrogen in all agricultural countries and is shipped all over the world for this purpose.

Until the breaking out of the war Germany was the greatest producer of sulphate of ammonia of all the countries, having surpassed the English production two or three years ago. The total German output for the year 1913 was 548 000 tons, England's maximum production being 432 000 tons, reckoning all forms of ammonia produced as the sulphate. The United States stands third in this rank, having produced 220 000 tons in the year 1915, the largest production recorded to date. Chemically pure sulphate of ammonia will contain about 25.8 percent NH_3 and as ordinarily produced it contains 25 percent or over, this being a high degree of purity for a commercial article produced in large quantities. It is of a dry, granular consistency and lends itself well to use in fertilizer mixtures. It can also be dried and ground and used as a direct application for top dressing growing crops. It is the most immediately available source of chemically combined nitrogen that the country has at its disposal and is one of our most valuable natural resources from this point of view. It is estimated that the nitrogen stored up in an acre of the ordinary four-foot vein of bituminous coal is sufficient to fertilize the acre of land above that coal liberally for a period of 3840 years. Unfortunately, all the nitrogen contained in the coal is not available for recovery, a part being lost because of the necessary amount of coal left in the mines and a further portion being lost in the conversion of the coal to coke and the recovery of ammonia. Allowing for all these losses, however, there still remains enough nitrogen recoverable in the form of ammonia sulphate to maintain the fertility of an acre for the period of 640 years. With these figures in mind we can appreciate the importance of the waste that is now going on in the carbonization of coal in the beehive coke oven, and furthermore, the great economic waste that takes place in the consumption of bituminous coal in the ordinary manner.

The question of ammonia recovery has taken on new importance because of the conditions developed by the war, and the imperative need for nitric acid in warfare. As you are all probably aware, nitric acid is the *sine qua non* in the making of modern explosives.

A number of years ago the great German chemist, Dr. Ostwald, discovered a method of oxidizing ammonia to form nitric acid. The process was a simple one, involving the passage of ammonia gas together with sufficient air, through a heated tube in the presence of a platinum catalyser. This process was never developed to any extent commercially, as enough nitric acid was always to be obtained from Chilean nitrate of soda, and at a relatively low cost, so that there seemed to be no financial inducement. The matter, therefore, lay dormant.

On the outbreak of the war, Germany was confronted with a critical condition in her nitric acid supply. Her annual imports of nitrate, amounting to 850 000 tons, were cut off. Not only was it necessary to supply its place in agriculture and in chemical manufacture, but a new demand had arisen for nitric acid for explosives. So far as information has reached us in this country, Germany has turned to the Ostwald process, or some development of it, and is now obtaining her nitric acid from ammonia by oxidation. We are told that she is now consuming from 250 000 to 300 000 tons of nitric acid per year for explosives, of which only 10 000 tons is obtained by the arc process of nitrogen fixation, the balance being obtained from ammonia derived from calcium cyanamid or produced synthetically by the Haber process.

Germany has for years recovered all the ammonia available in coke production. Therefore no room existed for expansion in that direction. But in the United States we are annually wasting over five hundred thousand tons of sulphate of ammonia that is produced in beehive coke manufacture but not recovered. If half of this were recovered we would have a sufficient addition to our present supply to equal the present German consumption for munition purposes, as above stated.

The development of the arc process for the direct recovery of nitrogen from the air, as done in Norway, offers many difficulties in this country. Chief among them is the lack of large water powers lying within our borders where power in large quantities could be produced at a price low enough to make continuous operation feasible in time of peace, even with Government support.

The production of calcium cyanamid, as done at Niagara Falls, is more attractive, but Niagara Falls is on our border, open to attack. Moreover, from cyanamid we obtain only ammonia, which we can more easily obtain from coal. The retort coke oven plants lie at well scattered points in the interior, and are not open to enemy attack.

It seems to me that the point on which stress should be laid, and on which Government support should be elicited is in the development of the process for ammonia oxidation. With that cleared away our own natural resources would become available

GAS

The gas produced from the distillation of coal in the by-product coke oven is essentially the same as ordinary illuminating gas. A fair average analysis of such gas is as follows:

	%
Hydrocarbons	5.8
Methane	40.8
Hydrogen	37.6
Carbon Monoxide	5.6
Carbon Dioxide	3.7
Oxygen	.4
Nitrogen	6.1
	100.0

Generally speaking, the gas will run from 600 to 700 B. t. u. per cu. ft. and will have from 14 to 16 candle power. It is capable of being used for all the purposes to which ordinary city gas is put, that is to say, not only may it be used in ordinary gas burners, stoves, heating ovens, etc., but it can be used for power in gas engines and can be transported long distances under pressure. Its illuminating value is due principally to the benzol and other higher hydrocarbons which it contains. In order to obtain the maximum illuminating value in coke oven gas a method of operation is frequently resorted to, which is known as the division of gases. The first portion of the gas given off from an oven of coke is, of course, the richest in illuminating as well as in heat value. Therefore, it may be readily understood that if the first portion of the gas from each oven is kept by itself in one system of mains and the later, leaner portion of the gas carried through a separate system of mains, the first gas will be much more valuable for general city purposes than the leaner gas. It is understood, of course, that the present system of heating the coke ovens is with a portion of their own gas. For this purpose the illuminants are by no means necessary, so the oven heating suffers no appreciable loss and the disposable gas is afforded a decided gain where this principle of the division of gases is practiced. The two gases remain distinct all the way through the condensing and scrubbing processes and the clean gas comes from the condensing house in two separate mains. One is led back to the ovens for firing them, the other is piped away for whatever purpose it may be desired. Roughly speaking, the proportion of gas under modern conditions is about half and half, that is to say, of the 10 000 cu. ft. of gas which a net ton of coal is usually supposed to deliver, about 5000 feet is used for heating the ovens and 5000 feet is disposable. With the shortened coking time that now prevails a greater proportion of gas is disposable, only about 4000 feet being necessary to heat the ovens in some plants. Usually the separation of the gases is made at the oven, proportioning the two quantities as nearly as may be by manipulating the valves, more rich gas being taken, if anything, than is necessary. If more oven heating gas is needed the rich gas can be by-passed in the fuel gas holder.

This plan of increasing the strength of the rich gas by taking the unessential portions from the poor gas, has been carried even further where benzol recovery is practiced, by scrubbing the lean gas to obtain its benzol, and adding this benzol as an enricher to the rich gas; in fact, where benzol is recovered, it has been found expedient to remove all the benzol from both gases and deprive them of their troublesome napthalene, and thus greatly facilitate the transmission of the gas in cold weather. After the benzol has been purified it is returned to the rich portion of the gas and a better and cleaner gas is thus obtained.

The usual type of condensing house for treating coke oven gas does not include purifiers to remove the sulphur. For the portion of gas used in heating the ovens the presence of sulphur is of no moment, and if it is possible to dispose of the surplus gas for usual city purposes, this in most cases has been done through the existing gas company and the purification from sulphur is attended to by them. In a number of instances the capacity of the district where the coke ovens are located to consume illuminating gas is far behind the production of the coke ovens, and other uses must necessarily be found. In some cases this has been done in the open hearth steel works, in the various heating furnaces, soaking pits, etc., accessory to steel mills, or in ordinary boiler firing. A much more desirable and economical use is, of course, in the internal combustion engine, where a great economy in the production of power may be obtained.

Although the by-product coke oven consumes nearly one-half of its own gas production, the surplus gas produced is usually very large in quantity because of the great amount of coal treated. The relation between the surplus gas production at such a plant and the consuming capacity of the ordinary sized town is not generally appreciated. A town, say, of 50 000 inhabitants, where gas is generally used, may possibly consume 5 000 cu. ft. per inhabitant per year, or about three-quarters of a million feet per day. A blast furnace producing 100 tons of pig iron per day would require a by-product coke oven plant of this size, and while a furnace of this capacity would be all right as far as it went, it would be something like the Ford among automobiles—good enough, but not anything to brag about. It will, of course, be recognized that it is a great advantage to by-product coke oven operation to be able to sell its gas for city consumption, where the price ranges from 60c to $1.00 per thousand to the ultimate consumer, rather than for purely fuel purposes in competition with coal. This may be the better appreciated when it is explained that the value of coke oven gas is about four cents per thousand cubic foot when used in competition with coal at $1.25 per ton for firing boilers, or where the coal is gasified in gas producers. Where more advantageous methods of disposal are available much higher prices may, of course, be obtained. In fact, from a broad economical point of view, the use of such gas under steam boilers is wasteful and is a sacrifice of a high grade product to a low grade use.)

BENZOL

I have already referred to the recovery of benzol from coke oven gas. This is, in fact, the main source of all the benzol produced, although coal tar is usually credited with containing the benzol, which forms the foundation of so large a portion of the coal tar chemical industry This is also true of the products allied to benzol—the toluol and xylol. Crude benzol, as obtained by washing this coke oven gas, is in reality a mixture consisting principally of these three. The process of recovering the benzol consists in washing the gas with a heavy oil, usually derived from coal tar or petroleum "straw" oil, until this oil is charged with the crude benzol, when it is removed from the circulating system and distilled at such a temperature as to drive over the benzol and allied vapors without disturbing the original washing oil. This oil may then be cooled and returned to the circulating system. The type of washer used for this purpose does not differ in any essential particular from that used in washing the gas with water to obtain the ammonia, the principle being to expose as large a surface of the washing oil as possible to the gas to facilitate absorption. The quantity of crude benzol contained in gas varies from two gallons per ton of coal carbonized to very much less than this, according to the volatile matter in the coal. The subsequent treatment of the crude benzol to separate it into its various fractions is carried out by fractional distillation between limited temperatures. Ninety percent benzol, which is the usual commercial standard, is that product 90 percent of which will distill over at 100 deg. Cent. or lower.

The production of benzol from coke oven gas has been extensively carried on in Germany and the large amounts of benzol so secured have been one of the main raw materials for their highly developed coal tar chemical industry. The surplus benzol was used as a motor fuel in place of gasoline, and under the present war conditions, benzol is the principal fuel for automobiles and similar engines.

Pure benzol is also the starting point for the manufacture of aniline oil and a wide range of dye stuffs, pharmaceuticals, etc., based on it. It is also important at present because from it pure phenol or carbolic acid can be synthetically produced. There is a great scarcity of phenol at present, as it is extensively used for making tri-nitro phenol or picric acid, an explosive, also for the peaceful use of making phonographic records.

The separation of the toluol from the crude benzol also supplies material for making tri-nitro toluol, a very important explosive used by the armies and navies of most nations in their shells, torpedoes, mines, etc.

The amount of benzol produced in the United States was very small until subsequent to the outbreak of the European war. If all the coal made into coke had been treated for benzol recovery, we would have had a production of about one hundred million gallons per year, on the moderate estimate of one and one-half gallons per ton of coal. It is stated on good authority, however, that the total recovery in 1913 was not more than four million five hundred thousand gallons, outside of that used for gas enrichment by the producer. The European War, however, not only cut us off from our foreign supplies of chemical and dye stuffs based on benzols, but immensely increased the demand for it because of the manufacture of war munitions in this country. Accordingly many benzol recovery plants have sprung into being, and this article hitherto, if not actually wasted, at least lavished on uses far below its potential value, is now in a fair way to come into its own. The Geological Survey in a recent report states that the output of benzol and light oils in 1915 was nearly 14 000 000 gallons and that with the completion of the new plants under construction the capacity will probably exceed 22 000 000 gallons per year. The price for refined has risen from 25c per gallon to 60c or upwards, while toluol, formerly in limited demand at 30c per gallon has risen to $4.25 per gallon and upwards.

As benzol is an excellent motor fuel, it is quite probable that any surplus existing after the close of the war can be readily absorbed for this purpose, although we may well hope that the development of our chemical industries will afford an adequate and more remunerative market.

CYANIDES

The presence of cyanogen in coal gas is generally attributed to the breaking down of ammonia in contact with hot coke or oven surfaces. Therefore, while the amount of cyanogen present depends originally on the amount of nitrogen in the coal, it has also an immediate relation to the heat of the coke oven or gas retort, in which the carbonization is carried on. High heats and exposure to hot surfaces encourage cyanide formation and low heats the opposite. The usual form in which cyanogen occurs is as hydrocyanic acid, *HCN*, thus

$$C + NH_3 = HCN + H_2.$$

The actual amount of cyanogen in a gas is small. Tests have shown that of the original nitrogen of the coal, amounting to one or two percent, only between one and two percent appears as cyanogen. A gas containing 130 grains of cyanogen per cubic foot can be worked profitably, it is said, provided the amount of coal treated approximates 200 tons per day.

In the usual method of purifying coal gas, by the use of iron oxid, more or less of the cyanogen is removed. Under favorable conditions the spent oxid will be found to contain enough to warrant treatment. This is usually done by chemical manufacturing concerns so located as to get suitable oxid from several works near enough to avoid heavy freight charges. These works purchase the spent oxid, on the basis of its prussian blue contents, and work it up, the final product being yellow prussate of potash, potassium ferrocyanide, or an equivalent form.

The complete removal of cyanogen from gas as a separate operation can be done in accordance with several different methods, as the Bueb, the Davis-Neill, Feld, etc., and is carried out on a commercial scale in a number of European gas plants. The Bueb process is perhaps the best known, and is employed at at least one of the two or three plants in operation in the United States, as well as at a number of European works. It consists primarily in washing the gas with a solution of ferrous sulphate, $FeSO_4$. This is done by passing the gas through a gas washer of one of the usual types, using the sulphate of iron solution as the washing liquid. As the presence of ammonia in the gas is essential to the reaction, the point chosen is previous to the ammonia washers. It is also necessary that the gas be first freed from naphthalin by passing through a washer in which a suitable absorbing medium, as anthracene oil, creosote oil or water gas tar, is used. The gas therefore passes through the naphthalin washer first, and then goes to the cyanide washer.

In the latter, the fresh sulphate of iron enters at one end and the gas at the other, the currents being opposed. The $FeSO_4$ reacts with the H_2S in the gas and iron sulphide, FeS, is formed. This in turn reacts with the CN and the NH_3, forming ammonium ferro-ferro cyanide.

$$2FeSO_4.7H_2O + 2H_2S + 4NH_3 = 2FeS + 2(NH_4)_2SO_4 \ldots (1)$$

$$2FeS + 2NH_3 + 6HCN = (NH_4)_4\, Fe_2(CN)_6 + 2H_2S \ldots (2)$$

Some soluble $(NH_4)_4\, Fe(CN)_6$ is also formed (ammonium ferro-cyanide), thus

$$(NH_4)_2\, Fe_2(CN)_6 + H_2S + 2NH_3 = (NH_4)_4\, Fe(CN)_6 + FeS \ldots\ldots\ldots (3)$$

The sludge liquor from the washer is treated in a still and then neutralized with sulphuric acid. It then contains an insoluble double ferrocyanide of ammonia and iron, plus ammonium sulphate, ferrous sulphate and free acid. It is run to a filter press, and the sludge removed in the form of press cake, ammonium ferro-ferro cyanide, or "blue."

$$(NH_4)_4Fe(CN)_6 + H_2S + A = (NH_4)_2Fe_2(CN)_6 + (NH_4)_2S \ldots\ldots\ldots (4)$$

$$(NH_4)_4Fe(CN)_6 + FeS + H_2SO_4 = (NH_4)_2Fe_2(CN)_6 + (NH_4)_2SO_4 + H_2S \ldots\ldots\ldots (5)$$

The final product is sold on its equivalent to potassium ferrocyanide, yellow prussiate of potash,

$$K_4Fe(CN)_6 .\, 3H_2O.$$

Under present conditions sodium ferrocyanide is made instead of potash, because of the high price of the latter.

TAR

The human mind is eager for paradox. That is why it seizes on the contrast between black, ill-smelling, obnoxious tar and the many colored, highly refined and variously useful products made from it. The wonders of coal tar chemistry are on every lip, and nothing is too impossible to be readily credited if tar is the starting point.

I am sorry that I cannot go very far with you on this inviting road, and I am afraid that what I have to show you will be rather prosaic by contrast. Our American coal tar industry has not yet reached the "Bird-of-Paradise" stage.

The removal of tar from crude gas was long a sticking point in methods of condensation and is still a criterion of good operation. As the gas cools, tar is deposited very readily, but the last traces of tar are not so easily removed. This is usually effected by passing the gas through a scrubber in which it is finely divided, together with a reduction in temperature to about 80 deg. Fahr., the latter being deemed essential to success. The temperature reduction has, however, been avoided by the use of a scrubbing device in which a jet of tar acts on the gas, and causes the tar mist to gather into drops which readily separate out. Until this difficulty was overcome the presence of tar in the gas prevented the adopting of direct saturation by which the ammonia is removed from the gas by passing through sulphuric acid, making sulphate of ammonia directly in place of washing with water and redistilling.

When coal is distilled in the gas retort or retort oven the lighter portions of the volatile matter in the coal go off as gas and heavier ones go off as tar. The dividing line seems to be about in the benzol-toluol-xylol series. Part of these go in the gas and part stay in the tar. It is not, however, a fixed line, but varies up and down according to circumstances. Nor is tar itself by any means a definite compound. Tars from different coals and more especially produced in different types of apparatus vary within wide limits. The more highly heated the surfaces over which the tar vapors pass on their way out of the retort and the longer the exposure, the heavier the tar. The percentage of free carbon is a fair indication of its quality, as the amount of oils and bitumens are apt to vary with it. Generally speaking, coke oven tars are low in free carbon averaging around ten percent, while gas-works tars are apt to be high, 25 to 30 percent and correspondingly lower in tar oils. Because of these variations and also because of the invariable presence of two or three or more percent of water there are few if any purposes to which crude tar can successfully be put without preliminary treatment, except to burn as fuel.

Therefore, for whatever purpose the crude tar is to serve, it has to undergo the process of distillation and probably admixture with other tars to correct defects in composition.

The distillation of tar is carried out in steel plate stills of cylindrical form, these being set vertically in Europe, but usually horizontal in the United States. A standard type is of half-inch plate, nine feet in diameter, and 20 feet long holding about 10 000 gallons. These are set in brick work with a fire box beneath them. usually several stills in a battery. The vapor from the stills is led away through a goose-neck to a condensing coil which is immersed in a tank of water, the temperature of which can be regulated. The separation of the distillation products is controlled by a thermometer placed in the goose-neck, cuts being made at certain specified points. For refined tar the removal of the water and a certain portion of the light oils is sufficient. Such refined tar is used in the saturation of felt for roofing, waterproofing and insulating purposes. In combination with soft pitch saturated felt is built into a foundation or laid on a roof for waterproofing or roofing, in successive layers.

It is also used in the manufacture of ready roofings, two ply. three ply and mineral surfaced. Another very important use of prepared tar is as good as a road application, or binder. For this purpose several different grades are made, each suited to a special field. They range from a thin tar to what is really a soft pitch of 100 deg. melting point.

When the distillation is to be carried out to the production of the various oils and pitch the separations are as follows in this country:

The first fraction is that which comes over below 200 deg. Cent., or until the distillate sinks in water. This is called light oil or crude naptha.

The second fraction comes over between 200 and 270 deg. Cent. and is called middle or carbolic oil. The third fraction includes the oil above 270 deg. until pitch of the required hardness remains in the still. It contains naphthaline and anthracin, and is known as heavy oil or creosote oil. It is extensively used in wood preservation under many and more or less complicated specifications.

The residue is pitch. In our American practice pitch varies greatly in hardness, the bulk of our production being the softer grades, used for roofing, paving, waterproofing and preservative coatings. Some hard pitch for use in fuel briquettes and similar purposes is also made.

The proportion of these five preliminary products in tar varies with the tar, but is about as follows:

Light oil	0.5 to 3 percent
Carbolic or middle oil	5.0 to 8 percent
Creosote or heavy oil including anthracin oil	20 to 30 percent
Pitch	60 to 75 percent

I have already mentioned the various uses to which the crude products are put and will now run over some of the products derived from them by further treatment, and their uses. I may say here that these cover a wide range and are by no means confined to dye stuffs and explosives.

LIGHT OIL

From this benzol, toluol and xylol are obtained as already explained and in addition a number of different solvent naphthas, also some phenol, creosol and naphthalin.

MIDDLE OR CARBOLIC OIL

From this we obtain tar acids or crude creosols and crude napthalin, also some creosote oil which is added to the heavy oil fraction.

From the first two we obtain phenol or carbolic acid, already referred to, a powerful antiseptic and disinfectant, also nitrophenol, the starting point for many dye stuffs, also trinitro-phenol or picric acid. This was used for a long time in medicine for the treatment of burns, as a textile dye and as an explosive in war. From the crude products we also obtain cresylic acid, and naphthalin, which is made into lumps, balls and flakes to keep moths out of woolen clothes. Napthalin is also converted into nitronaphthalin, from which many dye stuffs are made.

HEAVY OIL

In addition to the napthalin which has already been referred to, heavy oil contains anthracin, from which in turn comes alizarin and anthraquinon, from both of which a wide series of dye stuffs is obtained.

CORRESPONDENCE

Dr. W. H. Blauvelt:[*] I am glad to have had the opportunity of reading Mr. Atwater's paper, and regret that it is not possible for me to hear its presentation at your meeting.

Mr. Atwater's presentation of his subject is so comprehensive that it is difficult to add anything in the way of discussion which I have been asked to offer, but I have prepared the following notes or comments on several points that he brings out which I trust may be of some interest to you.

The indifference of the American people to the wide-spread waste of our natural resources is well known to all the world, and has long been a reproach to us. Not only have we thrown away all of the by-products that might have been produced from the 52 000 000 tons of coal coked in beehive ovens, but we have wasted a material amount of the coke also, as the by-product oven produces a distinctly larger yield of coke per ton of coal than the beehive. I recently made up some figures which showed that during a period of six years ending with 1913, the loss from these two sources was somewhat over $50 000 000 per annum. Those of us who are interested in the conservation of our mineral resources may comfort ourselves with the realization that this situation is being rapidly changed, and we may hope, within a very few years, to see at least half of the coke produced in by-product ovens. At least in the great centers of coke production the disappearance of the bee-hive oven is almost in sight.

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Mr. Atwater refers to the considerable trade in domestic coke. The use of this fuel is growing more rapidly than is realized by many. The present consumption is somewhat more than 1 000 000 tons per year, and the public is becoming accustomed to the small changes in manipulation necessary to make this fuel as satisfactory in domestic use as any other form of solid fuel. Where domestic coke is introduced for the first time in a locality it meets the usual difficulties arising from prejudice or mis-information, but once introduced it always stays. Of course, it has every advantage over soft coal, and in comparison with anthracite it contains much less ash, is easier to start, and responds more promptly to demands for more or less heat. It does not require special stoves or furnaces, if the proper size of coke is selected and it is burned properly, notwithstanding certain publications that have appeared under high authority to this effect. The City of Detroit and vicinity is alone consuming about 300 000 tons of domestic coke per year, and in practically no case is the stove or furnace especially designed for burning coke.

The surplus gas produced in the by-product oven is becoming an important factor in our industrial life. Not only is the use of this gas for lighting and heating our stoves growing as rapidly as the supply permits, so that several large cities, Milwaukee, for instance, are practically entirely supplied with coke oven gas, but also the industrial uses are becoming of material importance. For several reasons it is advantageous to locate the by-product coke oven plants at the blast furnace where the coke is consumed, rather than at the mines, according to the old beehive practice. Many of these iron works have steel works operating in connection with them, and the oven gas, stripped of its benzol, furnishes an excellent fuel, not only for the heating furnaces and soaking pits, but also for open-hearth furnaces. This last application was only experimental for a number of years, and several attempts were not successful, but during the last few years the application of oven gas to open-hearth furnaces has been worked out with entire satisfaction, and at least three prominent plants of open-hearth furnaces are now being operated with coke oven gas as the fuel, and the furnaces using this fuel are producing rather more steel than they did with the old producer gas. The combination of blast furnace gas for hot blast stoves and for furnishing power in gas engines and coke oven gas for soaking pits, heating furnaces and open-hearth furnaces is a very attractive one, and by the perfection of this combination we have taken a step distinctly in advance of our European competitors. It is not advisable to use oven gas under boilers unless there is no other opportunity to dispose of it. The breeze that is screened from the coke is a very satisfactory boiler fuel when properly fired, and it has little use for other purposes. The calorific energy in coal is utilized more efficiently and at less cost in boilers than in almost any other manufacturing operation, but for almost all other heating purposes around the steel works the oven gas is almost ideal.

The public has received a good deal of mis-information, especially through certain articles in the public press, regarding the situation in the United States as to the production of colors or dyes. It is not generally known that the production of benzol, and similar products from which dyes are made, have been for years more than sufficient to produce all of the colors and dyes used in the United States, if the amount produced had been applied to these purposes. For years millions of gallons of benzol were employed in enriching illuminating gas, for lack of a better market, when the enrichment could have been easily obtained from other sources, and the benzol set free for color making. Our tar distillers have stood ready to furnish all the naphthalene, anthracene, and other materials beside benzol that are employed in making colors, and the ruling prices were well within the color makers' reach. The real difficulty has been the same that will confront us after the war, if our government does not take the necessary preventative measures. In the dye-making countries of Europe it is recognized that combination is the life of trade, not competition, and while American manufacturers who combine their brains and efforts to carry out the development of a great industry are regarded as criminals under the law, in European countries they are encouraged, and in fact are almost compelled to combine for the best good of the industry and the nation. The dye industry needs not more raw material, but intelligent protection against destructive competition, and encouragement and safety for the large investments necessary to develop the complicated and highly technical manufacturers. American manufacturers have the money and the will, and American chemists the brains and the knowledge, and while the great color industry cannot be developed in America over night, we have all the factors here that are required for success, if properly combined and fostered.

The large increase in the production of benzol during the last two years will probably result in a considerable use of benzol as a fuel in internal combustion engines. It is about 18 percent more effective than gasoline, and can be used interchangeably with gasoline, in automobile engines for example, although in some makes of carburettors a slight readjustment of the air supply is required. Some very interesting experiments have recently been made by European authorities which show conclusively that the most efficient motor fuel of all is a mixture of equal parts of benzol and alcohol. Whether our farmers will ever realize the enormous possible yields of alcohol that can be obtained from their corn stalks and other waste material, remains to be seen, but these fuels may somewhat relieve the present trying situation of our great producers of petroleum oils in their endeavor to keep up with the demands for gasoline.

I cannot add anything to Mr. Atwater's able discussion of the methods employed in the distillation of tar and the products obtained therefrom, except to point out to you the rapidity growing importance of the creosoting industry, in which lumber is protected from decay. Only a few years ago it was an unusual thing to see a creosoted railroad tie, whereas now many of the prominent railroads lay no untreated ties.

From what Mr. Atwater has told you, and from the few comments that I have been able to add, you can see the important place that the products of the by-product oven are taking in our national life, and in view of the vital importance of our fuel supply and the wide range of uses which the by-product oven extracts from the coal, should we not recognize it as one of the important aids to that great economic problem of our time,—the conservation of our national resources?

Mr. F. F. Marquard:* I am sorry I cannot be present to participate in the discussion of this very interesting paper. I will, however, send herewith a short review of this subject as per your request.

The rapid development of the by-product oven is primarily due to the replacement of the beehive oven in the manufacture of metallurgical coke. Taking for example the Pittsburgh Coal with an average volatile of 33 percent, coking this coal in a beehive oven we have available coke of the following heat value:

2000 lb. Coal @ 13 000 B. t. u. per lb. coal = 26 000 000 B. t. u.

From the 2000 lb. Coal is produced 1200 lbs. dry screened furnace coke.

The 1200 lb. Furnace coke @ 12 500 B. t. u. per lb. of coke = 15 000 000 B. t. u.

Thus there is a loss in B. t. u. value per net ton coal coked in a beehive oven of 11 000 000 B. t. u., or 42.3 percent of available heat in the coal is lost in converting into beehive coke.

BY-PRODUCT COKE

2000 lb. Coal @ 13 000 B. t. u. per lb. coal = 26 000 000 B. t. u.

From 2000 lb. Coal is produced 1320 lbs. dry screened furnace coke.

Thus 1320 lb. Furnace Coke @ 12 750 B. t. u. per lb. Coke = 16 830 000 B. t. u.

6000 ft. Surplus Gas @ 550 B. t. u. per cu. ft. = 3 300 000 B. t. u.

3 gal. or 22 lb. Benzol & Homologues @ 18 900 B. t. u. per lb. = 415 800 B. t. u.

9 gal. or 90 lb. Tar @ 16 500 B. t. u. per lb. = 1 485 000 B. t. u.

Total, 22 030 800 B. t. u.

Thus there is a loss of 3 969 200 B. t. u. per net ton coal coked in the by-product oven, or 15.3 percent of the heat in the coal is lost by conversion into by-product coke and its products.

The coke breeze which amounts to 6 percent of the weight of the coal coked from high volatile coal will produce sufficient steam to supply all the power required for operating the by-product plant.

Thus it will be seen that for every net ton of coal coked there is a loss of 7 020 800 B. t. u. greater in the beehive as compared to the coking in the by-product oven, or an economic loss of 27 percent of the available fuel supply.

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*Superintendent Coke Works, Farrell Works, Carnegie Steel Company, Farrell, Pa.

Thus taking the figure as shown in Mr. C. G. Atwater's report from the United States Geological Survey, "Coal Distilled in Bee-hive Coke Ovens, 1915" as 52 100 000 net tons, a saving of 27 percent or a saving of 14 067 000 tons coal per year could have been effected if all the coal had been coked in a by-product oven.

COKE

It has been thoroughly demonstrated that the coke made in by-product ovens is more uniform in quality, lower in ash, and therefore more economical as a blast furnace fuel than is beehive coke from the same coals.

AMMONIA

The semi-direct process of ammonia recovery has been installed in all large plants and has proved very efficient. The gas contains about 0.3 percent H_2S which could be recovered and converted into sulphuric acid, which would more than meet the requirements in the ammonia sulphate production.

GAS

(Benzol extracted)

CO_2	1.6%
H_2S	0.3
O	0.4
CO	8.4
C_2H_4 C_2H_2	2.7
CH_4	30.5
H_2	49.7
N	6.4

The above is the average analysis of debenzolated by-product coke oven gas from Pittsburgh (Klondike District) coal.

The debenzolated gas will average 550 B. t. u. per cu. ft.

With coal at $1.25 per net ton, by-product coke oven gas would have a fuel displacement value replacing producer gas of 4c per 1000 cu. ft. of (550 B. t. u. per cu. ft.) which would give us 137 500 B. t. u. for 1c.

BENZOL

Since Benzol contains 138 000 B. t. u. per gallon it is obvious that the benzol in the gas when used as a fuel in the displacement of coal at $1.25 per net ton would be worth only 1c per gallon, so that the great economy effected by its extraction is very apparent.

In the operation of high-volatile coal, about 3 gals. of crude benzol is recovered per net ton coal coked: 20 percent of this is lost in its refining. The refined oils, about 2.2 gals. per net ton of coal, when separated into the pure form contain about:

75% Pure Benzol
19% Pure Toluol
6% Pure Xylol

This mixture begins to crystalize at –2 deg. Fahr. and makes a most excellent automobile motor fuel. A gallon of this motor fuel gives 20 percent more mileage than a gallon of 64-Gasoline. At the present time owing to the high price of benzol and toluol there is none being used for motor fuel, but its feasibility as an excellent motor fuel has been fully demonstrated.

The specifications of pure benzol is such that 95 percent of which must distill over within a range of 0.8 deg. Cent., in which shall be included the true boiling point of benzol, 81 deg. Cent. And that 100 percent shall distill over within a total range of 2 deg. Cent. Also when 20 c.c. of the pure benzol is washed with 15 c.c. of 66°Be′ sulphuric acid and shaken for one-half minute and let settle for 15 minutes, benzol shall remain water white, the acid only slightly colored. Pure toluol has the same specification regarding wash and distilling range, only on toluol the true boiling point is 110.2 deg. Cent. Corrections for emergent stem and barometer must be made in securing the true boiling point.

CYANIDE

The principal use of cyanide is in the form of *NaCN*, sodium cyanide, which is used for gold extraction on low grade ores. The by-product coke oven gas from Pittsburgh coal will yield about 1.9 lb. sodium cyanide per net ton of coal. Thus it is evident that the market would be easily overstocked if the cyanides were extracted from all the by-product gas, as the consumption of cyanide in this country and Mexico only amounts to about 12 000 net tons per year, which could be supplied from one plant alone.

At present prices, however, it would certainly pay to extract the cyanides if assurance could be gotten that same would continue long enough to build and operate the recovery plant.

TAR

In many places where by-product coke plants are close to steel mills tar is being burned in open hearth steel furnaces. By this practice they are able to produce a ton of ingot steel by the combustion of 32 gals. of tar.

Where coal has a value of $1.80 per net ton, tar has a value of 2.6c per gal. in displacing producer gas in open hearth steel practice.

Mr. C. J. Ramsburg:* It is with great regret that I am forced to submit a written discussion of this very interesting paper—but it is necessary for me to be away at the time of the meeting.

Very commonly the present activity in the construction of by-product coke plants is attributed to a stimulus given by the European war to the demand for by-products. It will therefore no doubt seem strange to you, in the light of this popular opinion for me to say that to the best of my knowledge and belief, there is not one coke plant being built today for this reason. The present activity is due to three factors.

First: It is now generally accepted by blast furnace managers that by-product coke is better than beehive coke for blast furnace purposes.

Second: Financial conditions accompanying the business stimulus instigated by the war, have enabled projects to go forward, which before had been recognized as extraordinary investments inevitably to be made.

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*Second Vice President, H. Koppers Company, Pittsburgh.

Third: It is realized by the industrial leaders in America, that efficiency begins with economical production of raw materials and that if we, as a nation are to hold our proper place in industrial competition, we must take advantage of every possibility for lower production costs, beginning with the largest of these.

There is little doubt that there has been awakened in America, largely through the effects of the war, an appreciation of what efficiency in scientific production methods may amount to. It is from these causes that there are in course of erection in America today, nearly 3000 by-product coke ovens, having a capacity of 12 000 000 tons of coke per annum. Mr. Atwater's paper on by-product utilization is therefore a most timely one.

There are three great fields open to the by-product coke oven:

First: As an auxiliary in blast furnace operation and steel manufacture, which utilize both coke and coke oven gas.

Second: As a source of coal gas for domestic and manufacturing uses, in conjunction with the manufacture of domestic coke, producer coke or furnace coke.

Third. For by-product recovery in power fuel manufacture, in which the coke is used in boilers displacing raw coal and the gas is used in gas engines.

This last field is one on which attention will be rapidly focussed, for there is no question that in the use of coal for steam production, we are burning up tar, ammonia, benzol, tuluol, and cyanides, as well as coal gas, all of which are materials of high potential value for other uses and whose waste could be avoided by use of the by-product recovery ovens.

Today at normal prices of by-products the value of the materials consumed with each ton of Pittsburgh Seam Coal, crediting the gas at natural gas figures amounts to over $1.50 per net ton.

No thinking man will deny that an economic advance will result when the coal is first coked and the coke then put in the firebox instead of coal.

Mr. Atwater brings this point out when he says, "It is quite probable that the future will see considerable extensions in this direction, as the other products of coal distillation become more desirable and justify investments."

The outlook for the use of by-product ovens in the future along these lines, as well as the use of benzol products and gas in increased quantities is exceedingly bright.

There are several points in the paper of which I would like to treat further, if time permitted.

An analysis of by-product gas is given as typical. This is not a typical gas today and it should be brought out that gas of this character is secured only in the earliest stages of the coking period.

If the hydrogen should be increased by ten percent and methane decreased by a like amount it would be typical of a coke oven gas secured by gas separation methods. Straight surplus gas would show still further increases in hydrogen and lower methane.

The gas analysis given shows a gas of approximately 680 B. t. u. per cubic foot whereas normal surplus gas, from rich coal by gas separation will not show more than 620 B. t. u., except under conditions which utilize an abnormal amount of lean gas for operation.

Mr. Atwater says that the average yield of gas per ton of coal is approximately 10 000 cubic feet of which 5000 cubic feet is surplus gas. You will be interested to know that in one of the latest plants put into operation in this country, with a mixture of 60 percent gas coal and 40 percent low volatile coal the yield of gas is in excess of 12 000 cubic feet per net ton, containing less than 5½ percent carbonic acid and nitrogen and measured through wet, rotary drum, positive meters. Of this gas, less than 40 percent of the heat value is used in coking. In this plant the total amount of heat carried off in waste gases and radiation is less than 4 percent of the heat value of the coal.

I believe it can be said correctly and with careful weighing of words that in design and operation, America is second to none in the efficiency of by-product coking. This is partially, though by no means entirely due to the exclusive use of silica brick in place of clay.

In connection with the utilization of by-products and particularly sulphate of ammonia, I wish that Mr. Atwater would give us some figures showing the yield per acre of various crops in Germany compared with yields in America and showing the relative amounts of ammonia used on each; his figures showing actual comparative results in America with and without ammonia are very interesting and convincing.

I believe that with these figures in mind, you can look upon the vast clouds of black smoke arising from the beehive ovens, and imagine them soon to be metamorphosed into increased yields of all these valuable crops, increased food supply for our growing city population, and increased chemical manufactures to replace imported goods. A discreditable waste, a source of atmospheric pollution, and a detriment to the public welfare will then be removed.

DISCUSSION

Dr. H. C. Porter:* I want to express my appreciation of Mr. Atwater's paper. I should like to have heard him say more in regard to the future use of benzol in this country when the war conditions no longer affect it. For a coal-products man he is remarkably modest in his estimate of the possible yield of benzol from coal in by-product ovens. He gives an average of 1½ gallons per ton of coal, which I think is too low. The low volatile coals give about that amount, but considering that, of all the coal coked in this country, including both beehive and by-product ovens, 65 percent or more is high volatile coal, a safe figure for the yield of benzol, even of the 90 percent purified grade which can be used as motor fuel, would be at least 2 gallons per ton and if 80 000 000 tons of coal should be coked this year, we would have a production of 160 000 000 gallons 90 percent purified benzol. This would be quite an item in motor fuel and consumption, and there is no question of the adaptability of benzol to motor use, as ample tests have proved.

I wish also that Mr. Atwater had said more about the application of coke oven gas for municipal supply. That is a business which is rapidly growing in this country. There are at least twelve cities in the United States now, or possibly more, using coke oven gas with entire success.

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*Chemist, H. Koppers Company, Pittsburgh.

MR. JAMES O. HANDY:* It is a great satisfaction to chemists to think of the wonderful progress that has been made in chemical industries, based on coal distillation, but there are still unsolved problems. Among these, the recovery of a larger proportion of the nitrogen which exists in coal is well worth working upon. Only a small proportion of the nitrogen is actually recovered. Some of the coal in the Pittsburgh Seam contains 1.4 percent of nitrogen. About 65 percent of the entire nitrogen remains in useless form in the coke. This is a shame, considering the value of ammonia compounds.

A new use of naphthalene has recently come to my attention. It is used in the manufacture of nest eggs, which are said to expel vermin and to help to keep hens in good condition.

Mr. Atwater spoke of the use of phenol, or carbolic acid, for the production of phonograph records. That is a very interesting development of the last few years. It is one of the resinous substances produced by the action of formaldehyde on carbolic acid. After these two chemicals have been mixed and heated for a short time they change into a very sticky substance which has the properties of a resin, and if the action is allowed to go on, it becomes a solid. It is used very largely in the manufacture of electric insulation as well as in the manufacture of phonographic records and a great many other things.

I think our Society is to be congratulated in having this paper by Mr. Atwater.

MR. T. V. SALT:† I have been much impressed with Mr. Atwater's paper and with the interest it has aroused. Several questions have been brought up that I do not think arise out of the paper but which naturally the paper would bring out in the minds of people who are interested in the business.

I think Mr. Atwater has shown that without the utilization of by-products there could have been no by-product oven business. I cannot think, however, that there is going to be any more remarkable development of these industries at the cessation of hostilities and for the next few years, than there has been in the past few years. The growth of these industries will of necessity have to follow along perfectly rational lines. It was pointed out that the use for benzol after the war is of course a very ready one. I do not think, however, that there will be anything like the production of benzol that has been touched upon tonight for many years to come, but if there should, it can be readily absorbed and will not make very much difference to the gasoline industry.

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†Vice President and General Manager, Allegheny By-Product Coke Company, McKeesport, Pa.

As regards the dye industry, there seems to be very grave doubt in the minds of those people most interested as to how rapidly that industry is going to develop in this country. There is a very great deal for it and a very great deal against it. I think myself that at the expiration of the war there is going to be the keenest kind of competition, and that competition is not going to be confined only to the iron and steel business, but will extend to the development of all the industries that the war has created in Europe. There will be all kinds of dye manufacturers over there. As it has been pointed out, the explosives that are being manufactured require benzol, and every town and village in Europe that can support a benzol plant has one. We know that the amount of benzol produced over there before the war was a great deal larger than we will produce for a long time. The European dye industry will have every facility and dyes will be much cheaper. There is nothing that they can make over there that they are going to buy. They will make everything possible and I do not look for any great spectacular development in the dye or any other business in this country immediately after the war. As Mr. Ramsburg pointed out, and I am glad he did, the development of the by-product coke oven industry in this country must be based on largely rational lines. Wherever there are conditions warranting the construction and installation and financing of a plant, it will doubtless be done. I do not think the war has had very much effect on what has been done any more than it has generally affected other business. Toluol and benzol were demanded; we had it and we are selling it, but I do not myself know of any one plant that has been built solely and exclusively to fulfill war contracts and I do not think there will be any built.

There is a possible development in the by-product coke oven business that has not been touched on this evening and which is important enough to warrant careful thought, that is, the utilization of by-product coke ovens for the manufacture of a domestic grade of fuel. This side of the business has not received the attention it deserves. Just so long as the by-product coke industry is only thought of in connection with the manufacture of pig iron, just so long will the industry be kept out of its biggest market. There are only about 30 000 000 tons of pig iron made per year. Of course at the present time we have a phenomenal tonnage, but I believe the rate of pig iron production has only developed about 1 000 000 tons a year in the last twenty years but at the most it is about 30 000 000 or 32 000 000 tons. There are about 500 000 000 tons of coal mined in this country alone every year.

Mr. Atwater pointed out what an economic crime it is to use coal in a crude form, and that has been generally conceded for some time, but there has been very little done to counteract it. The use of coke for domestic purposes will become more apparent and more of it will have to be used especially in cities where smoke ordinance committees are getting more exacting.

The development of the industry in the manufacture of domestic fuel requires generous capital and a rapidly increasing market for its by-products and we can see what effort is being put forth in endeavoring to find markets where these by-products can be utilized. The pictures we have seen tonight showing the results obtained from the use of sulphate of ammonia is greatly encouraging and such results speak well for an ever-widening use or ammonium sulphate.

A great deal of work is to be done before the by-product coke industry can be regarded by capital as a safe investment. So far nearly all our plants are in connection with the steel business and it is gratifying to me to see the interest that is being taken in the industry by all branches of technical men.

Mr. Atwater pointed out the different by-products obtained from a ton of coal, which products were valued by Dr. Porter at something like $1.50 per ton of coal. When we consider that this is greater than the value of the actual raw material at the pit mouth, the possibilities are stupendous. I think that with the minds that are now being brought into the industry, it is only a question of time until developments are made that will place the by-product coke oven industry on a strong and permanent business basis and where it can approach a market that it most naturally should take.

I want to thank the members of this organization for the privilege of listening to Mr. Atwater's paper.

Mr. Robert Linton:* In connection with the cyanide by-product has it been found possible to produce sodium or potassium cyanide such as is used in the treatment of gold and silver ores?

Mr. C. G. Atwater: I think I would be justified in turning that over to Mr. Handy. As far as I know the recovery of cyanide is in the form of ferrocyanide because of the use of sulphate of iron as a washing liquid. I do not think sodium or potassium cyanide is made from the ferrocyanide. Whether it can be or not under normal conditions I would rather refer to a real chemist.

Mr. J. O. Handy: There is no doubt that sodium cyanide can be made from ferrocyanides. Whether it is so made, I do not know.

Mr. C. G. Atwater: How about commercially?

Mr. J. O. Handy: I should think that would be a very useful source when it is available in material amount.

Mr. W. P. Flint:† I have been very much interested in the paper. My remarks are, perhaps, not legitimate as a discussion but Mr. Salt mentioned the by-product producers and the recovery of ammonium sulphate in them. There is an application of this type of producer which is interesting. Many coals contain so much ash that they are not fit to coke, but they could be used in the producer and the by-products recovered. I understand they have used coals that have 20 to 30 percent ash in this manner.

The gas from such producers makes good fuel for gas engines and can thus be economically used to produce electric power

*Mining Engineer, Pittsburgh.
†Mechanical Engineer, Pittsburgh.

MR. GUSTAV EGLOFF:* The speaker of the evening has brought out clearly the utilization of by-products from the manufacture of coke. Our company is highly interested in the by-product end from the benzol and toluol side due to their use for the making of the high explosives, picric acid and trinitrotoluene.

The demand for toluene is at present greater than the supply. To increase the output of toluene scrubbing devices are being rapidly installed for its recovery. Yet not rapidly enough to supply the requirements for the production of trinitrotoluene which the present war demands. This has necessitated the company searching for another source for toluene. This source has been found by cracking petroleum oils.

In the cracking of petroleum it has been found that certain temperatures, pressures and time the oil is in the heated area gave maximum yields of toluene, benzene and solvent naphtha. By changing the conditions of temperature, pressure and time one can control the yields of the substance desired. A piece of work conducted in the company's laboratory indicates the course of the cracking reaction to take place as follows: Solvent naphtha going to toluene, toluene to benzene, benzene to naphthalene, naphthalene to anthracene.

Since the coking of coal is a cracking reaction and the hydrocarbons in coal are mainly of a paraffin type then in the coking of coal it is reasonable to expect a similar course of reaction as in the cracking of petroleum. Since this is very likely true then the formation of toluene and benzene must follow the same laws of physical chemistry of temperature, pressure and length of time in the cracking area, from coal as from petroleum oil. This brings us to the question of the cracking of coal for coke to the point of asking would it be possible to control the cracking so as to get higher yields of benzene and toluene and still produce excellent coke? In other words can the laws of physical chemistry be applied profitably to the coking of coal so as to get a good coke and a maximum of the by-products, benzol and toluol?

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*Chemist Aetna Chemical Company, Pittsburgh.

Mr. W. L. Affelder:* I was rather surprised to read a few days ago an extract from a paper delivered before the American Institute of Mining Engineers by a Wisconsin steel man in which he upset that statement of Mr. Atwater to the effect that the Wisconsin Steel Co. have found out that by-product coke has not given the same results as beehive coke. The extract was rather fragmentary and I could not exactly determine why, but he very conclusively stated from the metallurgical standpoint that by-product coke was not as good as beehive coke. However, that is only one furnace.

A beehive man is a little out of the running tonight, with such a predominance of by-product men, so I am going to say but very little.

I have been doing a little figuring on the statement of the crime we have been accused of in the beehive industry. A number of times we have been accused of being criminals and I suppose we will have to plead guilty in view of these figures.

The Connellsville coke region is producing at the present time 450 000 tons of coke per week. The Connellsville ovens produce about two-thirds of the amount of coal charged in the shape of coke. In other words one-third of the charge, or one-half of the coke produced, is wasted, making 225 000 tons of the coal charged which passes into the atmosphere every week, amounting to 32 000 tons per day.

If that coal were loaded in railroad cars of fifty tons capacity it would make a daily train four miles long or an annual train, if the coke business continues as good as at the present time, of 1 440 miles, or 26 times the distance from Pittsburgh to Connellsville.

Mr. C. G. Atwater: It seems to me characteristic of most of the discussion that when they ask a question they proceed to answer it thoroughly and completely and probably much better than I could. If you were as conscious of the shortcomings of the paper as I am I would not get off so easily.

Mr. Ramsburg asked about the yields of crops in Germany and this country. That is not altogether a question of fertilizer. German crop yields are larger than ours in almost every case. It is not only that they fertilize better but they give it more attentive

*General Manager, Bessemer Coke Company, Oliver Building.

and careful handling. They have four people to support on an acre of ground where we have but one. They have to handle it more carefully and must get more yield. Conditions are very different in matters of agriculture. We get only an average of 12 bushels of wheat and they get 26. The reason we only get 12 bushels is because we farm Idaho and North and South Dakota and Washington and up in Canada with practically no tillage. The wheat is produced more cheaply than it is in Germany though the yield is so small. Those conditions are changing. It is very hard to make general statements about agriculture.

As regards my estimate of 1½ gallons of benzol per ton of coal I would say that I used both the figures 1½ and 2 gallons in different portions of the paper. I took the Geological Survey figure of 1½ gallons per ton when quoting their estimates. I presume they use this as a very conservative figure. I used the 2 gallons per ton in my statement of the probable yields. Two gallons is, I think, nearer correct on the average. As to the question of the yield of 12 000 cubic feet of gas per ton of coal, I would like to ask whether that is a net or gross ton.

DR. H. C. PORTER: Net.

MR. C. G. ATWATER: It is a very large yield and reflects a great deal of credit upon the development of the oven that made it. What is the volatile of that coal?

DR. PORTER: A mixture of 60 percent high volatile and 40 percent low volatile. The high volatile was what is known as Elkhorn coal from Eastern Kentucky, volatile 33 to 34 percent. The other was Pocahontas of about 18 to 20 volatile.

MR. C. G. ATWATER: It would average not over 38 actual volatile?

DR. H. C. PORTER: I have not figured the average volatile but I think it is close to 28 percent.

MR. C. G. ATWATER: That is the figure that governs the gas yield. That gas yield is very high and reflects great credit on the construction and operation.

I am aware that I passed over the matter of the by-product gas producer in rather a cursory manner. The reason was that the by-product gas producer has been before us a long time and does not seem to have realized commercially the brilliant promise of its earlier existence. I do not quite know why it is, although I have heard several men express themselves distinctly and I thought they had some experience. One reason is that it requires a large and expensive installation. Another reason is that to make so large an installation effective it must work all the time. Now very few gas producers are called upon to work all the time. Of course there is a large ammonia recovery there, 70 to 80 or 100 lb. of sulphate per ton of coal, and even higher. The tar is relatively of little value, that is to say while it may have valuable properties they have not yet been demonstrated. At present the by-product gas producer is not cutting a large figure either in ammonia production or in the carbonization of coal. It may do so more extensively in the future.

Aside from these points I want to say that I would not be taken too seriously about the economic crimes of those who burn gas under boilers. The burning of gas under a steam boiler, while it may be an economic crime, is quite different from a civil transgression. It is a matter in which the offender should be sympathized with rather than blamed. I think I know of no man who is burning coke oven gas under boilers who would not be willing to take 16c a thousand for it for some other purpose. I think that will close my reply to the discussion, unless some gentleman wishes to wrestle with me further in private.

THE MOBILIZATION OF MATERIAL AND INDUSTRIAL RESOURCES

By A. L. Humphrey*

A combination of circumstances covering the last few months seems to have placed me near the head of the conscription list, a fact that the committee which arranged for this series of military engineering lectures seems to have taken cognizance of. Notwithstanding my "unpreparedness" by experience or environments to undertake such a task, I responded to the committee's summons, as a matter of duty, the same as any patriotic American would respond to the call of his country in time of peril. The committee has very generously provided a double-track line for me to run on during the evening's operations, namely, The Mobilization of Material and Industrial Resources. In my travels, however, I have encountered so many tempting spurs leading to irrelevancies that I fear, before I conclude my remarks, you may feel that I have become hopelessly switched off and have completely forgotten my "running orders."

The four preceding lectures of this series have emphasized the great importance of the work done by the military engineer in military operations in the field, such as laying out and constructing field fortifications, entrenchments, concealments, obstacles, roads, bridges, maintaining communications with the base of supplies, mapping, etc. All these operations are carried on by a branch of the service so seldom mentioned in dispatches and news from the front that the casual reader is apt to overlook its existence.

The last of a series of Military Engineering Lectures delivered before the engineers of the Pittsburgh district in Carnegie Music Hall, under the auspices of the Engineers' Society of Western Pennsylvania. Presented on May 31, and published in the June, 1916, Proceedings.

*Vice President and General Manager, Westinghouse Air Brake Company, Wilmerding, Pa.

TRIBUTE TO ENGINEERING PROFESSION

So it has been in civil life in the lack of recognition of and credit for the work of the engineer. The engineering profession has contributed as much to the advance of civilization as any other, and to the civilian engineer belongs the larger portion of credit for great industrial advancements, transportation developments, hydraulic and electrical projects, structural achievements and for the thousand and one devices that contribute to the welfare of man and surround him with luxuries in leisure, safety in his avocation, convenience in travel, and, last but not least, a remunerative environment.

In view of this it is most appropriate that a body of engineers so representative as the Engineers' Society of Western Pennsylvania should consider, in all of its phases, the live and momentous question of preparedness.

PREPAREDNESS INSURANCE

We have heard expatiations on "preparedness," seen it used wholesale in advertising, and finally found it used in Congress as a basic argument for "pork" appropriations to widen dry rivers in territories where the ton-mile performance may fall not much behind that of northernmost Greenland—all of this and more until the word has lost its full meaning. However, at the risk of censure, I am going to venture an opinion on the urgent necessity for National Preparedness. Having been trained in the school of practical science and hard knocks I am a firm believer in preparedness insurance. The farmer of the vast plains of the West, who offers prayers that he may be spared from the ravages of cyclones, does not supinely stake all on his prayers, but believes in doing his part, too, by providing a cyclone cellar for the safety of his family. He does not incline to the belief that such preparedness so arouses the wrath of the Almighty as to increase the number and violence of cyclones. Nor does he begrudge the investment in this safety appliance—for, while he may never need it, like a man without a gun in the "wild and wooly" West, when he does he will need it "mighty bad." I believe that the patriotic citizens of this country would feel more at ease and would maintain a more calm repose, like the farmer snugly nestled in the cyclone cellar at the time of nature's upheaval, if they knew that we had at least a semblance of an army and navy that would keep off the ravages of foreign invasion.

In 1915 the per capita wealth of our country was $1965 and the cost of our Navy amounted to $1.41 per capita for that year. This indicates a rate of insurance which might readily be raised without material discomfort, and particularly when so doing means a matter of cents for insurance which might become a matter of dollars for tribute in case of invasion.

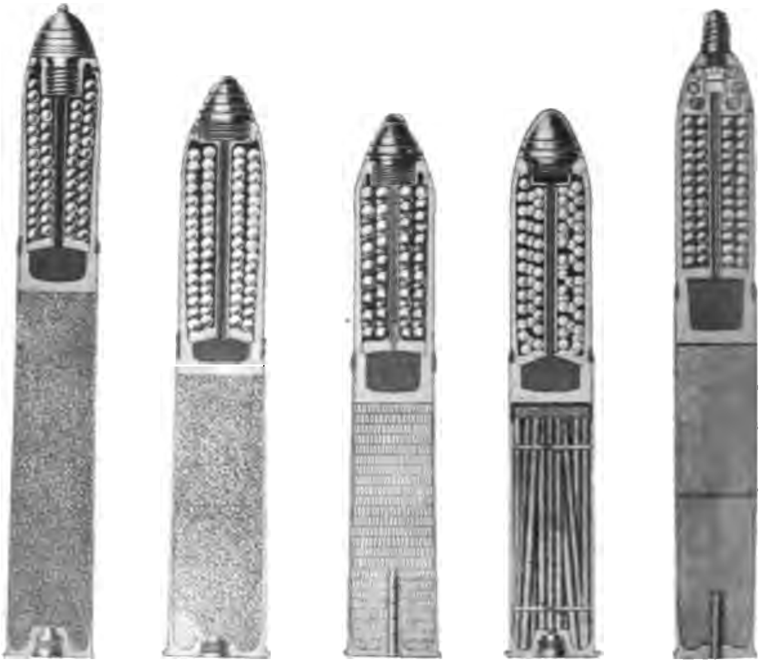
OUR LACK OF PREPAREDNESS

Many argue that we are sufficiently prepared. The practical refutation of this argument would cost dearly in lives and wealth. According to naval and military experts, our present supply of ammunition would last but four weeks of real modern warfare, and might be consumed in a matter of days.

We have read a great deal in the columns of the press, magazines, and in the *Congressional Record* as well, about the strength of our Navy. We have read of the wonderful construction of our new dreadnaughts and the picturesque accounts of their launchings; how, amidst the waving of flags and the blare of trumpets, the structure holding these fighting monsters in leash was knocked loose and how they glided down the ways into the water. At the bow stood a young lady, dressed in white, representing the State for which the leviathan of the sea was to be named. So loaded down was this incomparable fighting craft with statesmen and other important personages that the ways over which the vessel glided fairly creaked from the weight imposed. All of which offered a most impressive picture for the newspaper readers back home. But from the facts brought out in recent investigations and from information that I have been able to obtain from those who are in a position to know, the truth is that this war craft, representing an expenditure of from fifteen to twenty millions of dollars, which so spectacularly glided into the deep to protect American rights on the high seas, was not provided with ammunition enough to enable it to give a very creditable account of itself in case of a real combat.

THE PROBLEM IN MODERN WARFARE

The "Spirit of 1776" would undoubtedly be fanned into flame once more were a common peril to arise, but modern warfare needs that and vastly more, too. Conceive, if you can, of the scale of modern military operations. At the outbreak of the war in August, 1914, the German Army had six cannon for each 1000 infantry and cavalry and 6000 shells for each gun, making 36 000 rounds for each 1000 men. Taking four million troops in the first and second line ready to call, a total ammunition supply for artillery of 144 000 000 shells was on hand before war was declared, and *even this was not enough*. An American Army officer estimates that twice this initial supply has been manufactured and consumed since, making a total consumption of almost a half a


Russian Shrapnel 3-inch

British 18-lb. Shrapnel 3.29-inch

American Shrapnel 3-inch

German Shrapnel 77 mm 3.03-inch

French Shrapnel 75 mm 2.95-inch

Fig. 1. Various Types of Shrapnel Shell.

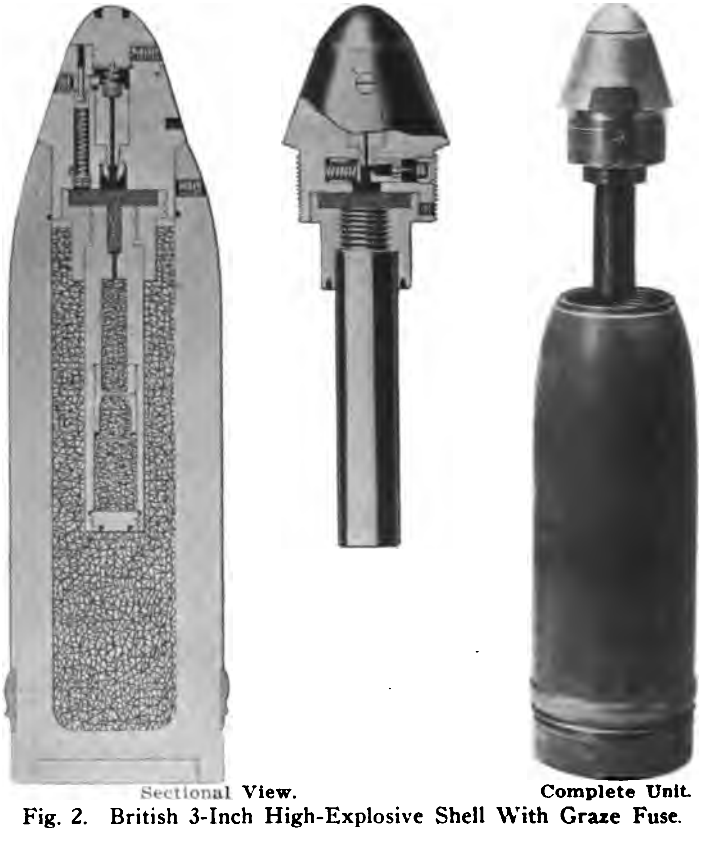
billion shells. During seven hours' time 80 000 projectiles were dropped into a space of 1100 yards front by 50 yards deep on the western front in Europe. The tremendous task this rate of firing imposes upon ordnance makes the modern gun partake of the nature of ammunition in its rapid depreciation and need for continuous replacement rather than its former nature of a permanent possession. In a word, an army numbering millions requires in its operations vast quantities of supplies of all kinds. Unless these supplies are forthcoming as needed the nation's defenders, however intelligently organized and splendidly trained, will be quite helpless. Such has been true of some of the nations engaged in the present war, most notably Russia.

SUPPLY OF RIFLES

While, as already pointed out, we are unprepared almost to the point of sinfulness in the matter of ammunition, the conditions with respect to rifles are even worse. From information I have been able to obtain, the present capacity of the United States arsenals for manufacturing modern rifles is between 800 and 900 per day, with the possibility of going as high as 1300 and 1400 per day. It requires no mathematical knowledge to compute that these plants, turning out rifles at the rate of 1400 per day, could only manufacture 500 000 in the course of a year's time, and that on this same basis it would take four years to provide rifles for an army of two million men—a very small army, by the way, if we should find ourselves in any serious "scrap" with a first-class power.

DANGEROUS CONCENTRATION OF MANUFACTURE

Until very recently the entire production of munitions of war, outside of Government arsenals, was concentrated in the vicinity of New York City. All of the materials, other than steel, entering into the manufacture of ammunition came from New England, principally Connecticut and Rhode Island. Our entire requirements in the way of torpedoes, so far as I have been able to learn, are filled from the same general neighborhood. Moreover, within less than 100 miles of the Atlantic seaboard are located our only gun-making plants, our ship-building concerns, our powder mills, our woolen and worsted mills. Last but not least, while many states in the Union contribute to the nation's supply of copper, fully 90 percent of it has to be shipped to New York or Baltimore, there to undergo the electrolytic process of refining. It makes one shudder to think that an enemy, after having effected a landing on the Atlantic Coast, might within a few days subjugate the entire territory mentioned and thus leave the rest of our vast and rich country absolutely helpless. The conditions with respect to some of these things have, of course, improved wonderfully during the past year. A number of large plants in Pennsylvania and Ohio have been equipped for, and are now turning out, ammunition in great quantities. The eastern part



Sectional View. Complete Unit.

Fig. 2. British 3-Inch High-Explosive Shell With Graze Fuse.

of Pennsylvania is also now contributing largely in the way of modern rifles. Much more remains to be done, however, to make the country at large independent of the highly specialized factories on the Atlantic seaboard, and there is no time like the present to spread the gospel of industrial preparedness among the manufacturing plants of the West and the Middle South.

One of the most important duties that the Government and its Advisory Boards should perform is that of selecting manufacturing sites in the interior where may be had immunity from attack in time of war. The plants for working up raw materials could probably be so distributed as to avoid the possibility of cessation of manufacture incident to an invasion. Large Government plants for manufacture of powder, as well as the other munitions of war, should be located in the interior and Middle West and arranged to provide for organization units capable of expanding or contracting at any time as requirements might demand. A reasonable number of expert workmen should be constantly employed in a small section of extensive plants and they would form the nucleus of the entire emergency organization in case hasty expansion should become necessary. This, in my opinion, would be the ideal arrangement. The Government should buy everything itself and, with machinery already in existence, it could equip for a very nominal sum extensive plants that would be capable of turning out enormous quantities of ammunition in a very short time, besides furnishing trained experts for independent plants. Large stores of raw materials of all kinds that go to make up complete appliances and that could be carried indefinitely without fear of deterioration from age could be maintained at these places.

CONSULTING BOARDS

Modern war is, more than anything else, an engineers' war. It is therefore to a mobilization of engineers that we must look for aid in this problem of preparedness. A notable beginning of such a scientific mobilization was made when the Secretary of the Navy appointed a body of engineers, distinguished beyond question, as a Naval Consulting Board and asked them to give their country the benefit of their brains and advice in upbuilding the American Navy.

We look upon the two great arms of our defensive organization, the Army and the Navy, with equal favor. While each has its own peculiar functions to perform, we, as citizens, know not one from the other and have a right to expect from each equal efficiency and high standard of performance. Let us hope that the wisdom of the step taken by Secretary Daniels in creating a non-partisan citizen board to co-operate with the highest naval authorities will be recognized by the head of the Army and that he will take similar action, so that the general staff may be aided and guided by the able assistance of a civilian organization. Such a military advisory board, composed of patriotic American citizens representing the various scientific and engineering bodies of the country, would insure to the Department of War the best thought and experience that can be put, by a body of engineers and scientists, into the good work started by the Navy.

SERVICE OF THE CHEMICAL ENGINEER

The part of the chemical engineer in modern civilization and in modern warfare merits the highest appreciation. Upon him devolves the duty of supervising the materials entering into the manufacture of cannon, rifles, ammunition and all supplies. Explosives particularly, the very king pin of modern war, are the fruit of his efforts. The work of the agricultural chemist is becoming of increasingly vital importance in war as well as in peace, for in times of national stress there may arise, as in Germany, the need for increased crops and stock production to offset the effect of cutting some lines of supply.

MOBILIZATION OF MATERIAL RESOURCES

In mobilizing our material resources it is necessary, first, to ascertain our probable needs in the event of war. We should then investigate and make record of the resources from which these needs may be supplied, and finally execute all preliminary measures necessary to stimulate production. The problem is a vast one, and fully equal in importance to the training of military personnel.

The supplies necessary are not limited to weapons, ammunition, food stuffs and clothing, but include the great bulk of the products of the farms, mines, forests and factories. Our material resources exceed those of any other nation and are ample for the prosecution of a great and protracted conflict. It seems to be the accepted theory of all those best versed in the subject, however, that we are very poorly organized from the point of view of military necessity. Through my active association with a combination of interests during the past two years, in an undertaking to furnish ammunition for European nations, I am perhaps in a position to appreciate more fully than those not so situated the seriousness of the lack of system that has so largely contributed to delays and extravagances in the preparation and manufacture of munitions for the belligerent countries. Fortunately for us as a nation, Europe, and not the United States, has paid for this inefficiency and for these shortcomings. Let us hope that the experience acquired in this direction by our manufacturers and engineers will be of undoubted benefit to our own defensive policy.

In the event of war the regular and volunteer forces of our country will be called at once to the colors and sent to the front as rapidly as they can be equipped. To expedite this equipment it will be necessary to have on hand a reserve of material, which calls for preparation in times of peace. This reserve should obviously be no larger than necessary; it will be great enough in any case. Its storage and care will be expensive. Some of it will become obsolete from time to time, some of it will deteriorate and become useless in storage. All of it will represent an investment paying no direct return except in case of war. The amount of each item of this reserve will depend, first, on the requirements of war, and second, on the predetermined rate of production and delivery subsequent to the outbreak of war. It is the province of the general staff to contemplate certain contingencies and the enrollment, training and equipment of successive levies of men to meet these contingencies.

CARD INDEX OF AMERICAN INDUSTRY

Under the direction of the Advisory Board Committee on Industrial Preparedness, thirty thousand American engineers are making a card index survey of American industry so that it may

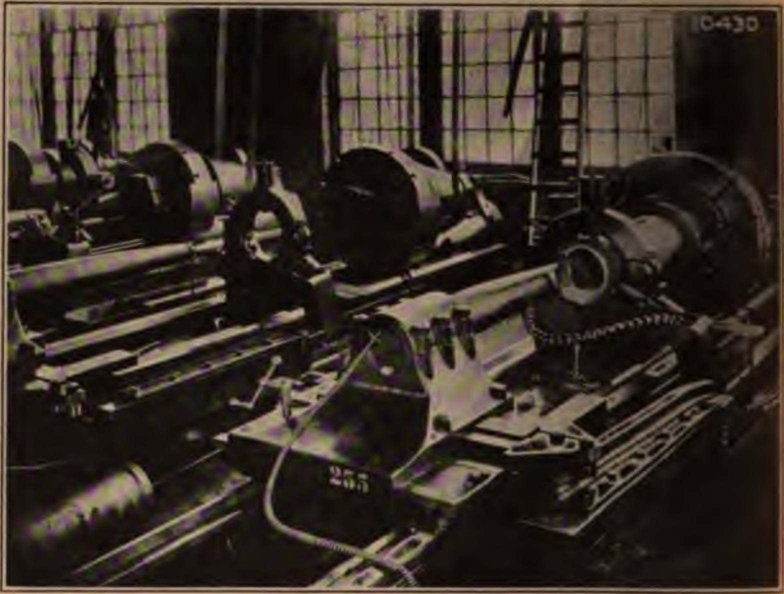


Fig. 3. Operations on 12-Inch High-Explosive Shell. Rough and Finish Bore Before Nosing.

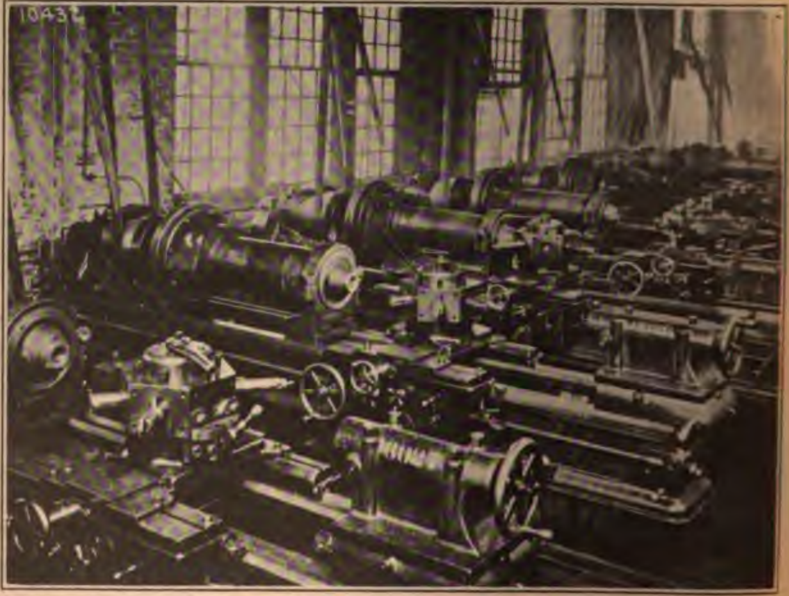


Fig. 4. Operations on 12-Inch High-Explosive Shell. Machining for Nose Bush.

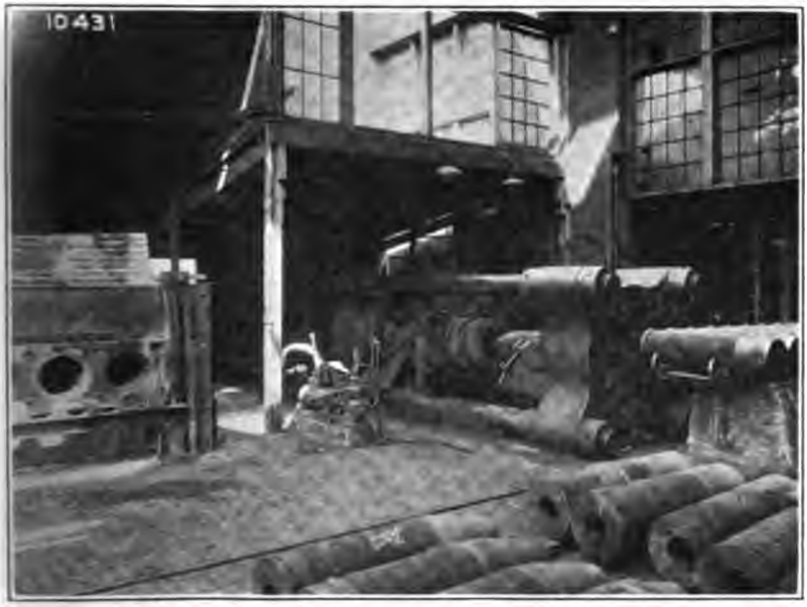


Fig. 5. Operations on 12-Inch High-Explosive Shell.
Nosing Shell.

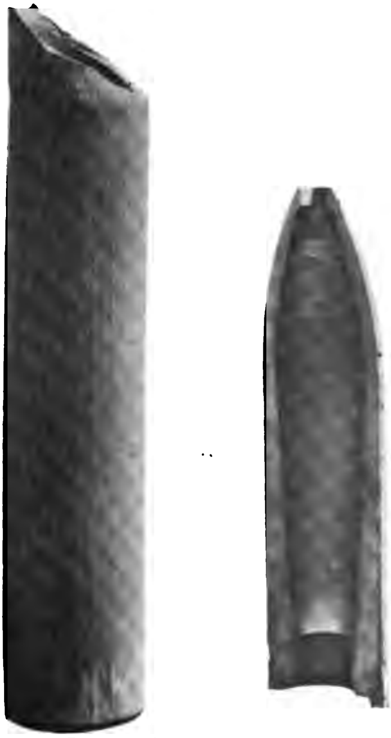


Fig. 6. Rough Forging and Finished Shell.

be prepared for its vital part in defending the country if need comes.

This plan of indexing involves:

First: Getting an accurate census of all manufacturing plants as to their present equipment and capacity, and their flexibility and needs for rapid expansion of output.

Second: Having each plant equip with the necessary tools and become familiar with its assigned work by making a small amount of munitions each year.

Third: Enlisting skilled labor in the service of our Government to make munitions in time of war instead of permitting it to go to the battle front.

ASSIGNED ANNUAL PRODUCTION

When this survey has been completed and when each manufacturer has been assigned a certain task that he must become proficient in performing, I believe we can confidently face any danger that may threaten the nation. There is no question that Germany's excellence in the organization of industries, by requiring each manufacturing plant of consequence to install the requisite machinery and train its employes in the making of shells, if only a small quantity each year, under the strictest supervision and subject to the most rigid specifications of the army, has been one of the principal factors that have enabled many of the achievements of her forces in the field.

In this connection, one of the greatest national services that could be rendered by the manufacturers now engaged in the production of ammunition for foreign countries and who, at great expense, have mastered the intricacies of the art, would be to impart the information so gained to managers of other plants that are likely to be enrolled in a general preparedness scheme. When organizing for the task assumed by the companies I have referred to, it would have been a great advantage if the plants which had previously engaged and become proficient in work of this character had given freely of their knowledge. I regret to say, however, that there was a disposition on the part of some manufacturers to be secretive, notwithstanding they could have supplied valuable assistance without monetary loss or violation of any business ethics. The volume of European orders at that time exceeded the capacity of the available manufacturing plants, yet the manufacturers in question absolutely refused to divulge any helpful information, even though one may have been a customer of the other along ordinary commercial lines, and the mutual relationship had been most cordial. It is needless to say that this narrow-minded and selfish attitude cost enormous sums of money and much valuable time. Contrast this attitude with that maintained by our brother manufacturers in the Dominion of Canada. The ammunition plants there threw their doors wide open, and those United States manufacturers who sought information not only had their requests gratified, but knowledge was gladly and liberally imparted in every instance.

Let us hope that the selfishness so pronounced among certain American manufacturers will not extend to the military requirements of our own Government, but that, on the contrary, all plants manufacturing ammunition will be placed on an equal footing, and impelled by motives of patriotism, if nothing else, will help one another out to the best of their respective abilities. So far as the one company that I am associated with is concerned, I am pleased to say that we have from the start given information freely to those who were preparing to do similar work and, in line with the general preparedness scheme, have not only extended invitations to individual manufacturers, but have designated a Railroad Preparedness Day on June 5th, on which occasion we intend to entertain the mechanical representatives of the railways of this country and afford them every opportunity to become conversant with the difficult and intricate art of making ammunition. Many railroad shops, with their heavy machinery and splendid organizations of skilled mechanics, could be quickly converted into ammunition factories and, as was the case in Canada, would undoubtedly be among the first to be called upon in time of need.

USE OF ARSENALS

With privately-owned plants delivering steadily a small output to the Government the arsenals of the latter could be used for testing and general development work, and for building the secret devices arising from such work.

PRIVATE OWNERSHIP

This plan would relieve the Government of a large burden. for a munitions plant with a private manufacturer would be made an adjunct of the main plant for producing the standard product. This would much reduce the overhead charges as compared with a Government plant of the maximum capacity necessary, forced to run at a load of perhaps but ten percent. As an example, the overhead charges for the production of armor plate by the Bethlehem Steel Company are carried in the greater measure by the mills and furnaces devoted to the standard steel product, and the Government therefore could not begin to produce armor plate at the costs possible in the private plant—quite aside from all considerations of "pork" and political inefficiency.

FAIR PAYMENT TO THE MANUFACTURERS

In return for his work the manufacturer should receive the costs involved in producing his assigned output. By this is meant the entire cost, which includes a fair return on the investment. I submit that to accept less than this would be suicidal; it would lead the industries of the country into bankruptcy and result in economic chaos.

FOREIGN CONTRACTS AND THEIR RELATION TO INDUSTRIAL PREPAREDNESS

Our country has made an excellent start along the line of industrial preparedness in that a large number of the most important industrial concerns of the country have during the past eighteen months contracted with European governments for the manufacture of the special lines of ammunition used in the present war. Special machines by the hundreds have been installed and thousands of men have been so trained that they have become expert in turning out shrapnel, rifles, field guns and high explosive shells of all sizes. These men and machines will form a most valuable nucleus for the preparedness propaganda and afford a most splendid opportunity for this country to avail itself of conditions now existing.

You have all, no doubt, read about the alleged enormous profits accruing to the manufacturers who have undertaken this work and the so-called "lead-pipe cinch" that they have on the output. It is not my intention to divulge any trade secrets or tell tales out of school, but to you, as interested engineers and business men, I am going to relate some facts which I believe have never been told before and trust they will not only be pertinent but interesting.

Most of the contracts with foreign nations were taken by combinations of manufacturing interests. The combination with which I happen to be associated consists of three extensive companies with well-organized manufacturing plants located in four geographic centers of the country, to wit, the American Locomotive Company, with plants at Dunkirk, N. Y., and Richmond, Va.; the New York Air Brake Company, Watertown, N. Y., and the Westinghouse Air Brake Company, Wilmerding, Pa. One contract called for five million shells, all for one country, two million five hundred thousand being for shrapnel shells and the other two million five hundred thousand for high explosive shells. In addition, contracts for small amounts were taken from some of the other countries at war. After the contract was executed, new buildings were constructed, materials, machinery and supplies of all kinds were contracted for and the actual work of manufacturing begun. I am sure when I tell you that not one of the three companies referred to was able to obtain, with but one exception, a single expert or employe who had ever worked in an ammunition factory of any description, you will be amazed. All three companies, of course, had high-grade organizations for the manufacture of their products, but with the exception of the one man referred to, there was no person in any of the organizations, from the presidents down to the lowest workmen, that had the least conception of the manufacture of projectiles. You will appreciate from this the value of the training these contracts have offered our American engineers and workmen in the art of munition manufacture, for in event of war we could, from the nuclei now available, do far more for our country than would have been possible eighteen months ago.

In order not to interfere with the standard line of manufacture it was necessary in very large measure to provide entirely new buildings and facilities. The line of machinery required for the economical manufacture of the projectiles was designed, manufactured, and installed, irrespective of the large bonuses and enormous prices demanded. The work was undertaken with vigor and determination to meet the guaranteed date of delivery, and you will certainly be astonished to learn that the company with which I am directly associated was compelled to spend between six and seven million dollars in constructing buildings, providing machinery, manufacturing jigs, gauges, patterns and special appliances and for the purchase of materials before one single payment had been made by the foreign governments. Assuming that the other companies forming our combination made corresponding expenditures, the total amount paid out in getting ready for the work was from twenty-five to twenty-eight million dollars before one cent of profit was received. This enormous expenditure will, I am sure, make you appreciate the serious responsibility that the officers of the different companies took upon themselves for the purpose of providing employment for their idle workmen and incidentally to put a little profit, perhaps, in the pockets of the stockholders of their companies. Many of you, no doubt, have read accusations in the press and heard speeches delivered by politicians and in the God we trust do-nothingites that preparedness was being backed and urged by the "Industrial Barons" of our country. I do not pretend to speak for the thousands of patriotic manufacturers and stockholders of the industrial institutions of this country by any means, but as an individual I hurl back the accusations and feel sure that I am expressing the views of thousands of others similarly engaged, when I say that in any contemplated dealings with our own Government we are not prompted by a desire for profit. On the other hand, we sincerely believe that this great country of ours should fortify itself against invasion. In case this nation ever becomes imperiled our patriotic manufacturers will respond nobly, prompted solely by the desire to serve the American people, who have made the great industries of this country possible, and whose co-operation is so essential for a successful preparedness undertaking. The much-

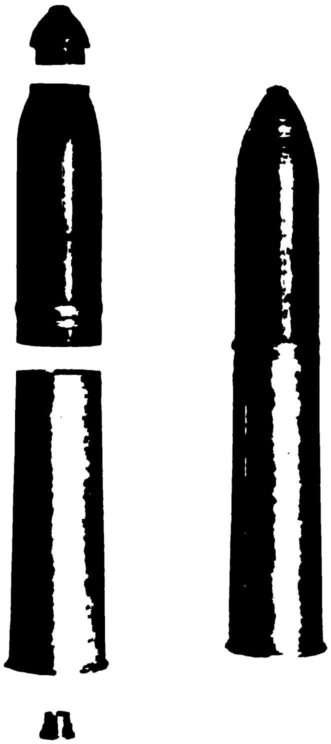


Fig. 7. Complete Unit.

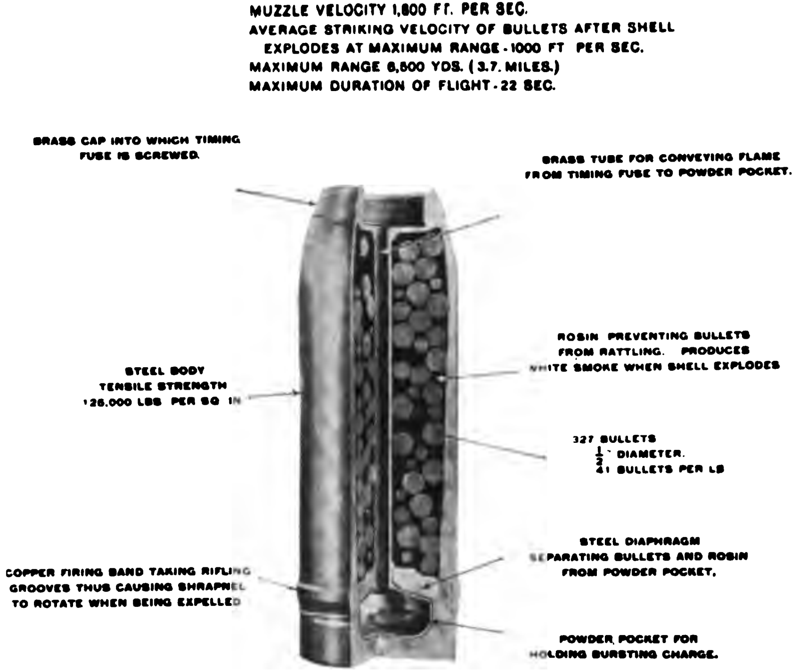

MUZZLE VELOCITY 1,800 FT. PER SEC.
AVERAGE STRIKING VELOCITY OF BULLETS AFTER SHELL EXPLODES AT MAXIMUM RANGE - 1000 FT PER SEC.
MAXIMUM RANGE 6,500 YDS. (3.7. MILES.)
MAXIMUM DURATION OF FLIGHT - 22 SEC.
BRASS CAP INTO WHICH TIMING FUSE IS SCREWED.
BRASS TUBE FOR CONVEYING FLAME FROM TIMING FUSE TO POWDER POCKET.
ROSIN PREVENTING BULLETS FROM RATTLING. PRODUCES WHITE SMOKE WHEN SHELL EXPLODES
STEEL BODY TENSILE STRENGTH 126,000 LBS PER SQ IN
327 BULLETS ½" DIAMETER. 41 BULLETS PER LB
STEEL DIAPHRAGM SEPARATING BULLETS AND ROSIN FROM POWDER POCKET.
COPPER FIRING BAND TAKING RIFLING GROOVES THUS CAUSING SHRAPNEL TO ROTATE WHEN BEING EXPELLED
POWDER POCKET FOR HOLDING BURSTING CHARGE.

Fig. 8. Section of Shell.

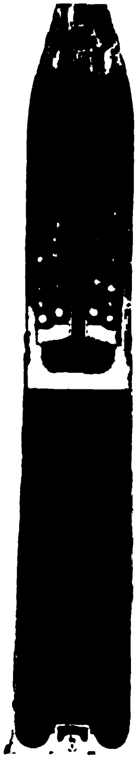


Fig. 9. Section of Complete Unit.

British 18-Pound Shrapnel.

maligned so-called "Industrial Barons" stand ready to contribute not only their wealth and resources, but their time as well, for the actual good of the cause.

There is being manufactured in this country at the present time in the ammunition line what is known as shrapnel, a projectile approximately 3-inches in diameter, high-explosive projectiles that range from 3-inches to 15-inches in diameter, rifles, field guns and rapid-fire guns. The greatest demand has probably been for shrapnel. In addition, thousands and thousands of tons of raw material for projectiles have gone abroad to be manufactured in the countries of Europe. There have been contracts let in the United States for from ten to fifteen millions of shrapnel and the same amount of high-explosive shells. The shrapnel are fired from quick-firing guns and used mostly in close range fighting. By referring to Figs. 7, 8 and 9 it will be seen that a complete shrapnel unit, taking as an example the British eighteen-pound type, consists of the shell proper, filled with 327 bullets of ½-inch diameter. This shell is expelled from the gun by the propellent powder contained in the cartridge case. It leaves the gun at a muzzle velocity of about 1800 feet per second. The time of explosion is governed by the time fuse, so accurately and delicately adjusted that the time of explosion can be set to take place at from eight-thousandths of a second to twenty-one seconds from the instant of firing. The specifications governing the manufacture and final inspection of this particular mechanism are such as would under ordinary circumstances certainly produce chilly lower extremities on the part of the average manufacturer unless he was accustomed to the intricacies called for in the specifications provided by the countries for whom the contracts were to be executed.

MEN NEEDED AT HOME AS WELL AS AT THE FRONT

It has been estimated that for every man needed at the front to operate the machines of actual warfare there are needed three men at home to furnish him with the supplies for his operations. Thus for an army of two million men at the front six million men are needed in the workshops to keep supplied the men in active service. When one considers that there are not more than 3000 truly expert gage makers in the country, the point where they can render most effective service is fully apparent. The work of the Committee on Industrial Preparedness then is most wise in listing our skilled artisans that they may not be foolishly sent to the front in the time of need and thereby impose starvation upon military operations. The enlistment of skilled labor is of vital importance, and all measures, also, which may be developed to imbue these men with a sense of their patriotic trust and honorable service to their country. It is certainly to be hoped that in our time of trouble we may be spared the humiliation recently suffered by England because of labor difficulties in an hour of such great national peril.

Surely it is just as essential that the workers of the country be mobilized as it is to mobilize the industries and material resources themselves, and let us hope that once skilled labor realizes that upon it rests grave responsibilities in case of national danger and that their constant and faithful attention to duty at the workbench may prove the salvation of our country, our men will rise nobly to the occasion and do honor to this great country even as do those who are actually shedding their blood on the field of battle.

RESTRICTIVE LABOR LEGISLATION

Right here let me draw attention to the insidious, lurking dangers in the way of restrictive labor legislation that have become so manifest to the manufacturers of this country who undertook at an enormous financial risk the manufacture of a commodity with which they were not familiar. I refer to the manufacturers who took ammunition contracts from European countries for the purpose of maintaining their organizations and affording steady and remunerative employment to men who had been operating on hours shorter than any known in this country for years. The absence of laws governing the hours of labor and output, together with the hearty co-operation of their employes, enabled the manufacturers mentioned to inaugurate a system for increasing production and for rewarding their employes on the basis of individual skill and efficiency. I have been informed by the representatives of foreign governments that the excellent results obtained from this system have amazed the world.

Through this freedom of co-operation between employer and employe the latter has been enabled to earn wages far beyond any former expectations. It has been my privilege to discuss this subject freely with heads of organizations that have undertaken the manufacture of ammunition, and in every instance I am informed the workingmen of this country have signified their willingness and desire to work together with their employer for the purpose of increasing output and thereby add to their daily earnings. I am sure the employes would not have fared nearly so well, financially or otherwise, had the contracts calling for the manufacture of the same commodities been with our own Government. Under the narrow, ill-advised laws upon our statute books covering the making of material for the United States Government—material to be used for the protection of our own national existence and to safeguard our own flesh and blood in the trenches, the flower of American citizenship—the hundreds of thousands of patriotic American workmen, only too glad to exert their best efforts for the cause of their country, would be permitted to work only eight hours per day. In addition they would be hampered by the narrow, impracticable, ill-advised legislation bearing on the question of efficiency in the manufacture of munition products for the United States Government, which prohibits the promotion of efficiency by any officer, manager, superintendent, foreman or other person having charge of work of or for the United States Government, in co-operating with an employe while engaged in such work or from using any instrument that would tend to record the movements of any employe for the purpose of adding efficiency. Such legislation prevents the designing and development of special machinery or the payment of bonuses or premiums for the betterment of either the employes or the Government. Measures of this character are so contrary to the spirit of Americanism, and so repugnant to the skilled workman who would be called upon to do the actual work in time of need that I feel constrained to pronounce them an insult to the American workingman and introduced only as a vote-catching measure pure and simple. The very fact that it is possible to get such legislation as this on our statute books is the best evidence that one of the greatest national needs today is the mobilization of statesmen at our National Capitol, who are broad enough, intelligent enough and patriotic enough to be guided by the spirit of common sense and square dealing in the discharge of their duties to their country and not to be swayed by the influences of the demagogue and so-called "vote controller." I want to go on record as saying that had the manufacturers of the United States been compelled to quote prices on ammunition contracts received from foreign governments during the past two years under the restrictions imposed by our own National Government it would have been necessary to bid from 25 to 50 percent higher than the prices at which the contracts were actually taken, and it is the opinion of those in a position to know that such prices would have been prohibitively high and that the business would not have been procured. Unhampered by foolish laws as they were, however, the mechanics engaged in the manufacture of ammunition have been able to earn from 50 to 100 percent more than has ever been earned by the same class of workmen heretofore.

WOMEN IN THE WORKSHOP

In Europe the emancipation of woman has advanced very rapidly due to the vast war which has called the men to the front and has left much of the work at home to be done by women. In our country also the sphere of woman's activity has widened recently, and this is of great significance in our problem of training and mobilizing skilled labor. As a concrete illustration I wish to refer to the Recording & Computing Machines Company, of Dayton, Ohio, which took the contract for the manufacture of five million time fuses for the Russian Government. This work was undertaken by an organization entirely inadequate for the project. As time went on they found it impossible to obtain not only experts, but male help in general. Like the combination that I have referred to and with whom I am associated, Mr. Ohmer, president of the Dayton concern, decided that on account of the impossibility of obtaining skilled assistance in carrying on the new line of work, and not being able to obtain male workmen in sufficient numbers he decided to employ female help quite generally throughout the entire plant. After a personal investigation of the successes at present being attained at Mr. Ohmer's factory, I am glad to record the fact that his company is now employing approximately six thousand people and is manufacturing from twenty thousand to thirty thousand time fuses per day. These fuses are meeting the specifications in every particular and 80 percent of the work is being done by women gathered together from Dayton and vicinity. These women are employed in every class of labor, with the exception of that requiring more physical strength than they can muster. Between three and four thousand of them are running screw machines, drills, mills, lathes, and many of them have learned in a short period of time how to grind their own tools. They are not only doing men's work, but a study of the time sheets shows that many of them, who are working entirely on piece work, are doing with ease quite a good deal more work than the men whom they displaced. It is gratifying to say that the women mentioned are being paid according to their efforts, many of them earning as high as $5.00 to $6.00 a day. To quote Mr. Ohmer, the company "makes no discrimination in the pay as to whether it be for man or woman. Since the time women have been put in the places of men assigned to other duties, the product has multiplied by leaps and bounds."

MATERIALS

Materials required for the conduct of war may be classified under two general heads:

First: Commercial materials, tools and appliances; that is to say, those which are manufactured and used in large quantities in times of peace;

Second: Materials or equipment which are peculiar to warfare and are not ordinarily manufactured at all, or to a limited extent only for commercial purposes, and which cannot, therefore, be readily obtained on short notice.

The line of demarcation between the two classes cannot be definitely fixed. Examples of the first class are axes, barbed wire, automobiles, shoes, anaesthetics and dynamite. To the second class belong military rifles, portable entrenching tools, haversacks and pontoon boats.

The gathering together of material for the manufacture of war munitions means that a demand is made upon the resources

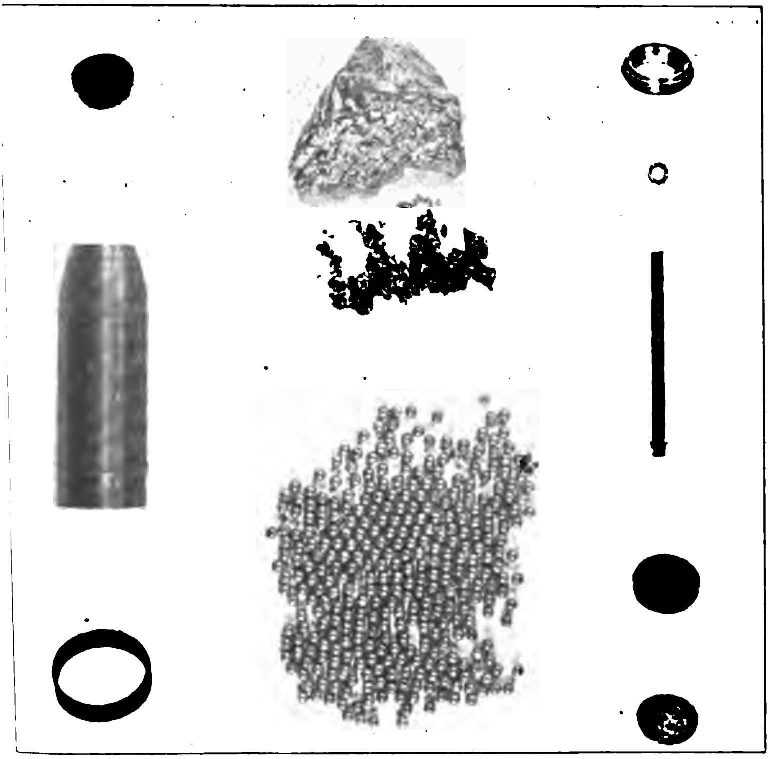


Fig. 10. Details of British 18-Pound Shrapnel.

of the country for an enormous amount of commercial material, much larger than is required in normal times. It also means a demand for special materials. By special materials, I mean those which are manufactured in small amounts in normal times, but would be required during times of war in much larger quantities. In estimating the amount of a given material that can be obtained or manufactured in a certain period of time, it is necessary to not only judge as to the rate of manufacture, i. e., the amount that can be manufactured in a given period, but also where the raw materials used in the manufacture of the given article may be obtained. A great many materials are built-up materials; that is, the finished product is made or manufactured from several other manufactured products, which in turn are combinations of still other products.

For instance, take the manufacture of a complete shrapnel shell. It includes the cartridge case, the steel shrapnel shell and the time fuse. We estimate that it will take so many tons of steel to produce so many thousand shrapnel. In the manufacture of this steel it is necessary to have the ore, fuel, limestone, and blast furnaces for manufacturing pig iron. The next step is the manufacture of steel from this pig iron in the open-hearth furnace, and in addition to the pig iron we must have ferro-manganese at this stage of the operation. It would seem, judging from the experience of last year, that a large percentage of the ferro-manganese used here is imported, the price having advanced from $40 per ton to $1000 per ton. The question then is, can we make a suitable shrapnel with a lower percentage of manganese, or can we develop within our own borders manganese ore to such an extent that we can manufacture our own ferro-manganese in case of war?

Another item that might be mentioned in the manufacture of shrapnel is the composition of the bullets. In ordinary manufacture, bullets contain 12.5 percent antimony and 87.5 percent lead. Practically all of this antimony is imported, and in case our foreign supply was shut off, we would have to find a substitute or develop mines within our own borders. It can be readily seen that each item in a given part of apparatus should be traced back to its original source to determine whether the supply is sufficient. If not sufficient, means should be employed by the Consulting Boards to cover this deficiency or find a substitute that will make the given article in a satisfactory manner.

From our own experience, when going over the specifications offered by various countries, we have picked up weak points which show that the factor of quantity of available material was not considered. For example, in addition to the question of antimony, which it might be impossible to obtain if we were at war with the country from which it is now being secured, there was a certain specification from one of the Allies that provided for a quantity of magnesium powder in the manufacture of shrapnel. It was found upon investigation that there was in the United

States not more than one-fourth the magnesium powder required to supply the demand called for in this particular specification. After some months of negotiations and delay, the foreign government was notified that the magnesium powder could not be obtained and that in order to fill the contract it would be necessary to eliminate this item from the specifications, which was finally done, thus making the specifications similar to those of other European countries.

CONSIDERATION OF THE MARKET FOR EACH MATERIAL

The nature of the market for each material must be carefully considered. The ideal condition is a market sufficiently broad and flexible that a sudden increase in the demand of 10, 20 or 100 times the normal requirements will not send the price to a prohibitive figure. A hard and unyielding market for a material requires that the question of some adequate substitute be thoroughly investigated and that the governmental specifications, through staff approval, be made sufficiently adaptable to accommodate practicable substitutions. This feature was particularly absent in the specifications provided by the foreign governments in their applications for munitions in this country. In our negotiations we found certain compositions of brass desirable for the manufacture of the timing fuse. Perhaps it will be found that the abnormal demand for large quantities of a certain grade of copper and spelter would make it difficult to obtain the required amount, or at least the price might be so high as to prevent the manufacturer from making a reasonable bid. In this case, is it not possible that some other alloy could be used? From experience in the manufacture of our standard line of apparatus we are firmly convinced that the metallurgist and the chemist can work out problems of this sort.

A very important factor which enters into this question is the workability and the machining properties of a given material. In the specifications provided by some of the foreign governments we have found that, while the material specified was ideal, so far as tensile strength, ductility and other properties were concerned, it would be so difficult to machine or work in the shop that the labor expended would often be three or four times the amount that

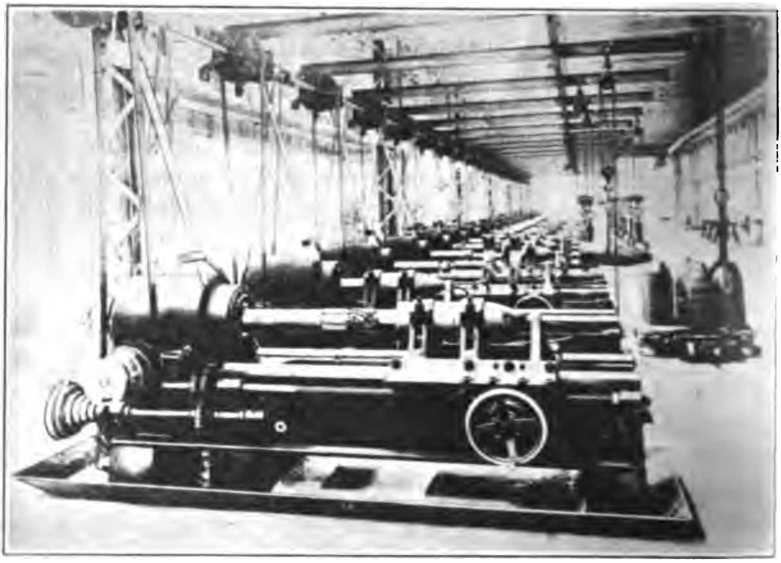


Fig. 11. Special Machines Required in Manufacture of Large Shells.

would have been necessary had the specifications been prepared with this most important item in view, as well as supplying the necessary physical properties. This particular feature is often neglected or ignored by engineers in specifying a given material for a given purpose. After finding a material which has the suitable physical properties for the service intended, the question should be asked: How does it machine; how does it work in the shop; how does it forge? It means that the engineer must get in touch with the shop end—the practical end—before he finally adopts a material for a given purpose. All of this would come within the province of the Advisory Boards already suggested.

TIME REQUIRED TO START MANUFACTURE

The average American industrial plant cannot change in a day, a week, a month, or in fact several months, its regular output to a new line unless careful and intelligent preparation be made in advance. Without such preparation a year might elapse before a plant could be placed in condition to produce munitions in an

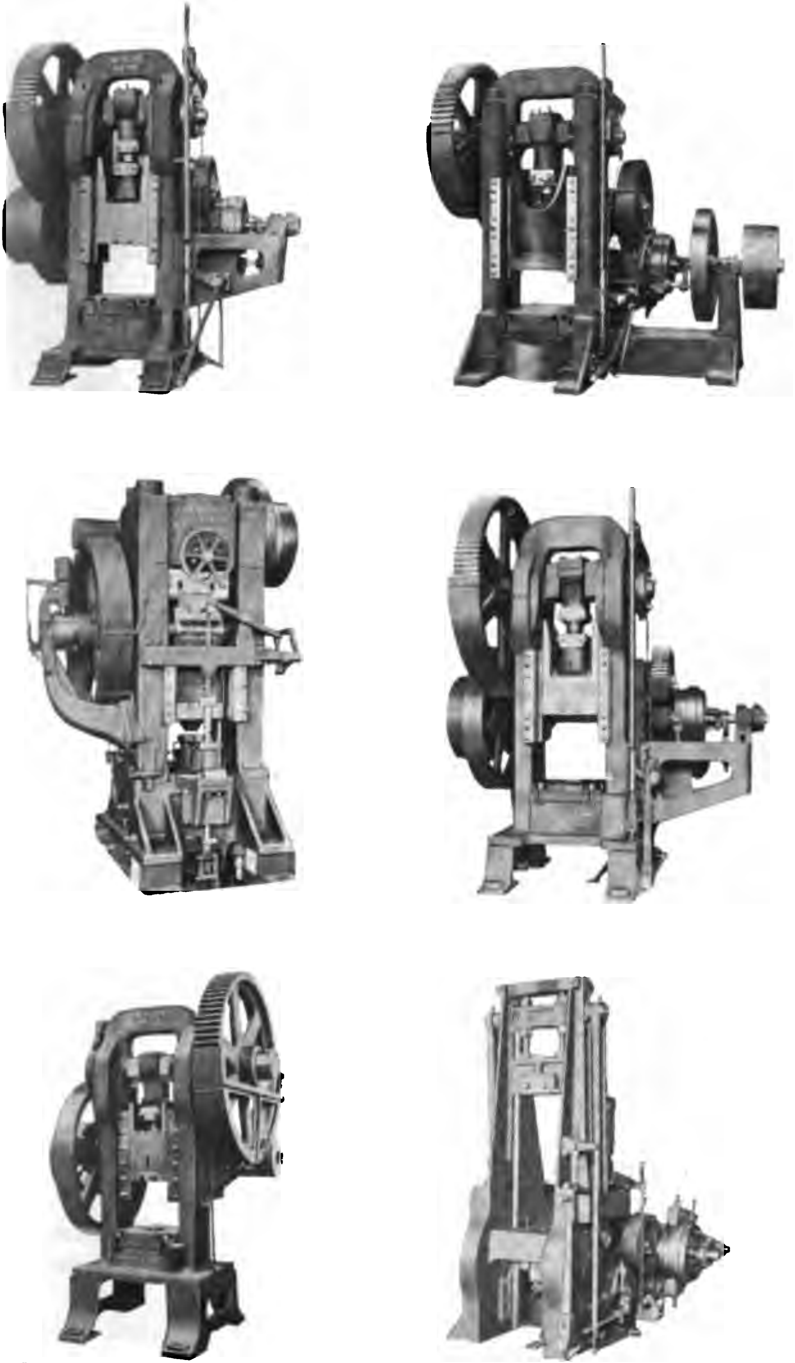


Fig. 12. Special Presses Required for Manufacture of Cartridge Cases. Twenty-three Required for One Complete Unit, Sufficient for Output of 10 000 Per Day.

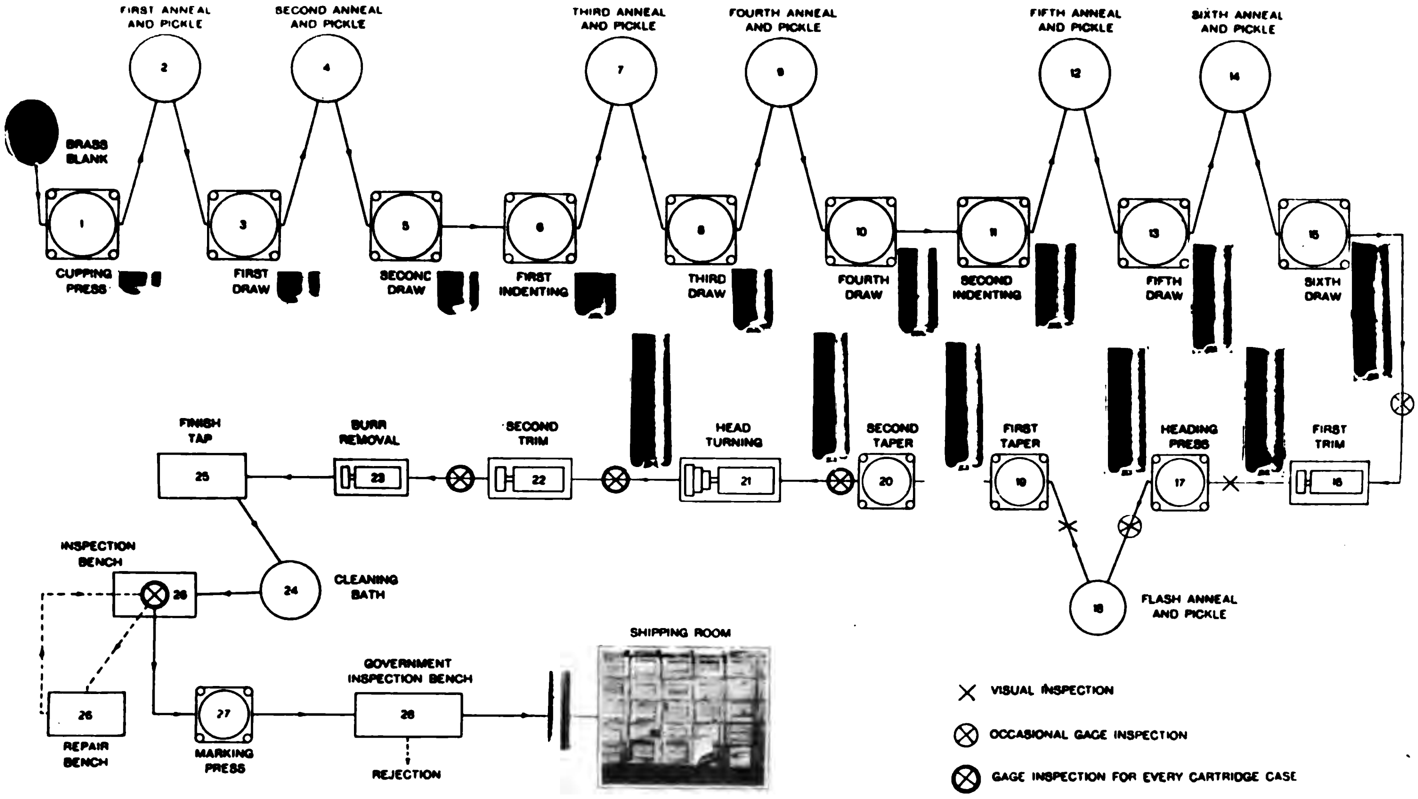
efficient and economical manner, and then it might be too late.

As an illustration of the foregoing let me quote from a prominent manufacturer of the mid-West:

> "The thing that has stirred up the business men of the Middle West during the past eighteen months has been the lesson they have learned in the making of war materials. It points a very vivid moral to all our people. It all looked very easy when it started a year and a half ago. The plant with which I am associated in Cleveland got an order for 250 000 three-inch high-explosive shells. It was a simple enough looking job, just a question of machining. The forgings were shipped to us and we were to finish and deliver. It began to dawn on us when the forgings came that this whole order that looked so big to us was less than one day's supply of shells for France or England or Russia, and we felt that in eight months by turning our plant, which is a first-class machine shop, onto this job we could fill the order. In a little while we got up against the process of hardening. That—and mark what I say—was fourteen months ago. To date we have shipped and had accepted 130 000 shells, and those, about half our order, are not complete. They still have to be fitted by the fusemaker, then fitted in the brass cartridge cases with the propelling charge, and somewhere, some time, maybe, they will get on the battlefield of Europe. Up to the present none of them has arrived there.
>
> "Now this is the situation in a high-class, efficient American plant. This is what happened when it turned to making munitions of war. The same thing has occurred in so many Middle Western plants that their owners have made up their minds that if they are ever going to be called upon for service to their own country they must know more about this business. They feel that they are now liabilities to the nation and not assets in case of war. Proud as we may be of our industrial perfection, it has not worked here, and the country—particularly you in the East—may as well know it."

Speaking more generally, the type of ammunition which may be under consideration for manufacturing in a certain plant, in order to get production started most quickly should correspond as nearly as possible to the line of work which the plant has been regularly producing, as naturally the general equipment and arrangement of machine tools will not only correspond more nearly to what will be required, but the experience of the organization, including the men in charge, as well as the workmen, can be adapted more readily to work which is approximately of the same size as they have been accustomed to.

Let us consider this matter from two viewpoints:


BRASS BLANK
FIRST ANNEAL AND PICKLE
SECOND ANNEAL AND PICKLE
THIRD ANNEAL AND PICKLE
FOURTH ANNEAL AND PICKLE
FIFTH ANNEAL AND PICKLE
SIXTH ANNEAL AND PICKLE
CUPPING PRESS
FIRST DRAW
SECONC DRAW
FIRST INDENTING
THIRD DRAW
FOURTH DRAW
SECOND INDENTING
FIFTH DRAW
SIXTH DRAW
FIRST TRIM
HEADING PRESS
FLASH ANNEAL AND PICKLE
FIRST TAPER
SECOND TAPER
HEAD TURNING
SECOND TRIM
BURR REMOVAL
FINISH TAP
CLEANING BATH
INSPECTION BENCH
REPAIR BENCH
MARKING PRESS
GOVERNMENT INSPECTION BENCH
REJECTION
SHIPPING ROOM
1
2
3
4
5
6
7
8
9
10
11
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× VISUAL INSPECTION
⊗ OCCASIONAL GAGE INSPECTION
⊗ GAGE INSPECTION FOR EVERY CARTRIDGE CASE

Fig. 13.

Where a new concern is started without buildings, equipment or organization; and

Where a going concern starts with a sufficiently large organization from which a nucleus can be taken for the handling of munition work.

First: In the case of an entirely new plant, careful consideration must be given to the following points:

(*a*) A preparatory schedule on the basis that the contract is sufficiently large to warrant installation of the most suitable types of tools for the work.

(*b*) Plan of buildings most suitable.

(*c*) Organization.

(*d*) Labor costs.

(*a*) The condition of the machinery market and the urgency of the contract will largely determine the type of machines installed. In every case, where possible, automatic or semi-automatic machines should be given preference in order to eliminate the necessity for any degree of skill on the part of the operators, and thereby reduce materially the losses due to error of the individual. Careful consideration should be given to every detail of the manufacture before decisions are made as to the types of machines, a thorough time study made and the most logical sequence of operations worked up and scheduled. Too great stress cannot be placed upon this feature, as any changes it may be necessary to make after machines have been ordered will result either in considerable loss or inefficient manufacture. Grouping of the machines should also be gone into very carefully to avoid unnecessary handling and permit the product to travel from one operation to another with the least amount of labor.

(*b*) With the above data settled, the size and type of buildings required can be quite readily determined. As a concrete example I might state that a building 65 by 600 feet, of wooden construction, concrete foundations and sills, with a capacity of 20 000—3⅜-inch by 11½-inch cartridge cases per day of 20 hours, equipped with necessary machines, and an additional building 65 by 150 feet for annealing and pickling, were erected and ready for operation in about eleven weeks.

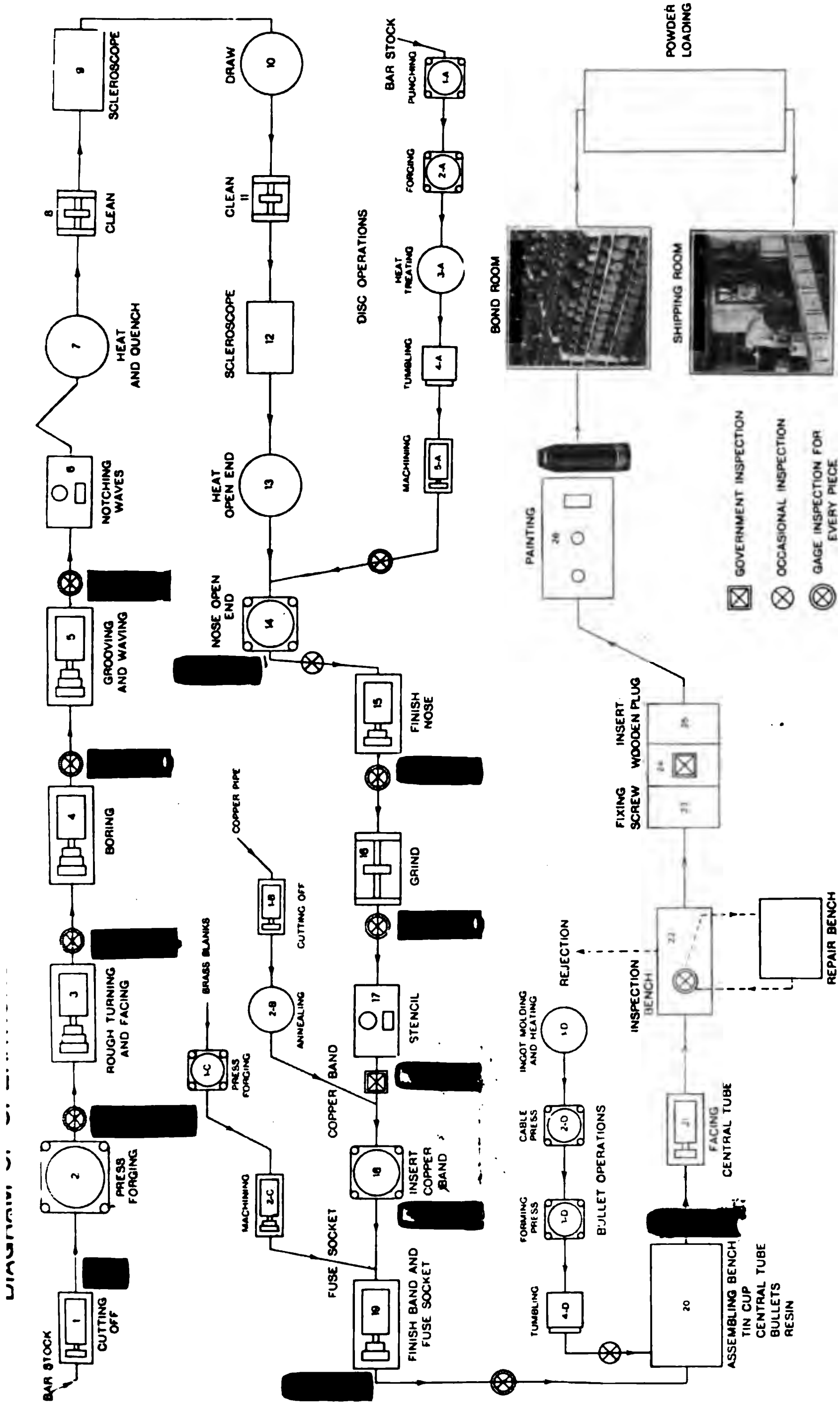
BAR STOCK
CUTTING OFF
1
PRESS FORGING
2
ROUGH TURNING AND FACING
3
BORING
4
GROOVING AND WAVING
5
NOTCHING WAVES
6
HEAT AND QUENCH
7
CLEAN
8
SCLEROSCOPE
9
DRAW
10
CLEAN
11
SCLEROSCOPE
12
HEAT OPEN END
13
NOSE OPEN END
14
FINISH NOSE
15
GRIND
16
STENCIL
17
INSERT COPPER BAND
18
COPPER BAND
FINISH BAND AND FUSE SOCKET
19
FUSE SOCKET
BRASS BLANKS
PRESS FORGING
1-C
MACHINING
2-C
COPPER PIPE
CUTTING OFF
1-B
ANNEALING
2-B
DISC OPERATIONS
BAR STOCK
PUNCHING
1-A
FORGING
2-A
HEAT TREATING
3-A
TUMBLING
4-A
MACHINING
5-A
INGOT MOLDING AND HEATING
1-D
CABLE PRESS
2-D
FORMING PRESS
3-D
TUMBLING
4-D
BULLET OPERATIONS
ASSEMBLING BENCH
TIN CUP
CENTRAL TUBE
BULLETS
RESIN
20
FACING CENTRAL TUBE
21
INSPECTION BENCH
22
REJECTION
REPAIR BENCH
FIXING SCREW
23
24
INSERT WOODEN PLUG
25
PAINTING
26
BOND ROOM
SHIPPING ROOM
POWDER LOADING
GOVERNMENT INSPECTION
OCCASIONAL INSPECTION
GAGE INSPECTION FOR EVERY PIECE

Fig. 14.

(*c*) Organization: If possible, someone who has had direct experience in the manufacture of the munitions under consideration should be placed in charge, but in case such a man is not available, one with extensive experience in duplicate manufacture and with sufficient knowledge and practical experience to keep in mind the human equation, as well as the technical problems to be met, should be considered.

(*d*) Labor costs: It might be well to mention here that before starting manufacture to any extent a careful time study should be made of each operation in detail, determining the strokes per minute of the machines, cutting speeds, best type of cutting tools, taps, etc., and the approximate piecework prices at which the work can be done, based on a certain earning per hour.

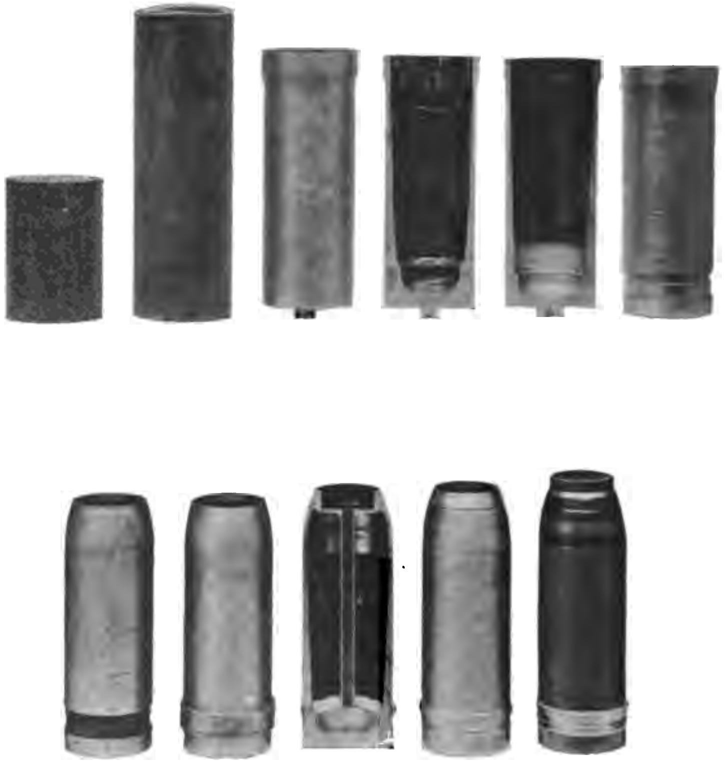

Fig. 15. Evolution of Steel Shrapnel Shell.

Second: Where an attempt is made to take a going concern and convert it into an ammunition factory it will be found necessary in practically every case to discard at least 50 percent of the tools used in ordinary commercial work, providing the order is large enough to warrant installation of the most suitable machines. In our own case the percentage of tools suitable for this work in any one department did not amount to possibly more than two percent. Assuming that in no instance would orders be considered for less than 200 000 of any one size shell, it would be a more economical proposition to consider installation of machinery for the particular contract, as by getting a uniform installation sufficient reduction will be had in manufacturing cost to more than offset the initial cost of machinery, and a better product will be obtained. The purchasing of such machinery as would be flexible enough to meet manufacturing conditions on standard products should be kept well in mind.

Where this work is undertaken by a going concern the question of organization is more simplified than in a new concern, as men having suitable training for various phases of the work can be transferred from the standard departments. This is true as to the men in charge as well as to workmen, and will result in getting production started in a much shorter period than where an organization must be built up from the bottom.

Under these conditions the time required to equip our plant and have production in full swing required approximately four months. In general, this will depend upon the supply of labor and the availability of the necessary machinery.

A great deal will depend upon the machine tool market as to how soon a plant may be placed in full operation. Fig. 10 shows some special machinery necessary for the production of 3-inch cartridge cases on the scale of 10 000 per day. As machines like this cannot be improvised from standard types nor supplied in a very short time the need is most apparent for having plans carefully worked out in advance and all the large time-consuming elements cared for while time is plentiful.

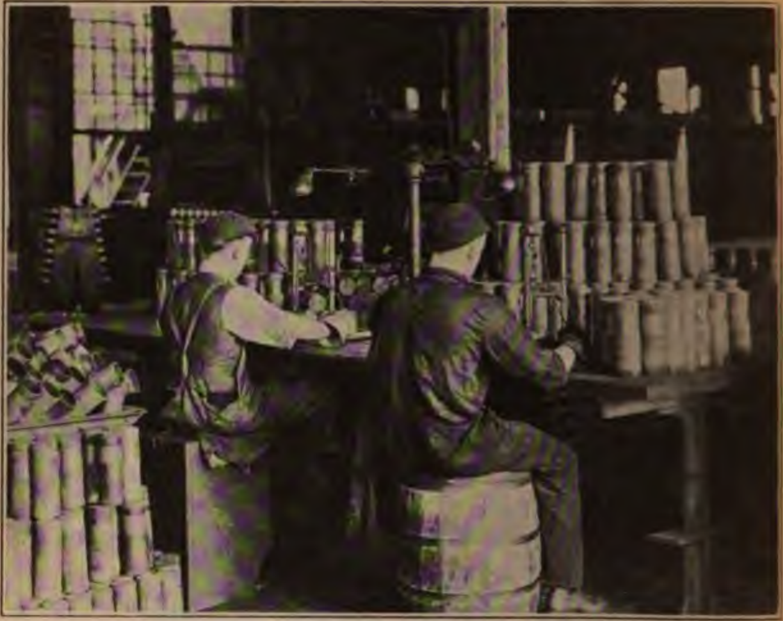

Fig. 16. Testing Each Shell With Sclerescope.

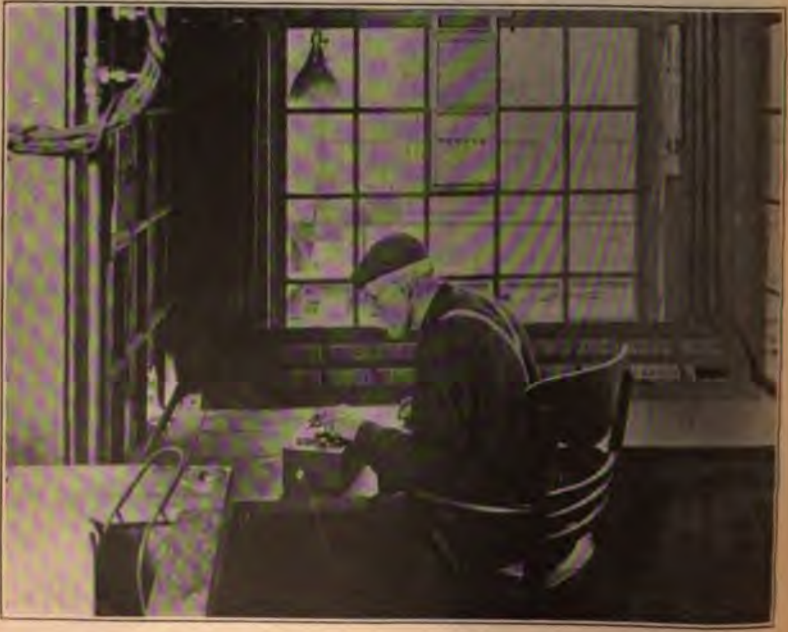

Fig. 17. Pyrometer Switchboard.

GAUGES, JIGS, SPECIAL TOOLS

One of the most crying needs in the recent mobilization of American industrial talent in the service of foreign governments has been for gauges, jigs, machine fixtures and other special tools. In building up an organization no feature is of greater importance than the tool room and gauge department, as a very large number of special tools and attachments to standard machines are required to obtain accurate work as well as output, and since these are necessarily of a special nature and in many cases must be worked out by experiment, the character of the tool room will determine, to a large extent the results to be obtained in production.

In the manufacture of the combination time and percussion fuse, Fig. 18, 170 gauges are required to make a complete set, and we are using seven sets for an output of 10 000 fuses per day of 20 hours, or a total of 1190 gauges. A total of 243 separate operations are required to complete the details and 32 special fixtures and jigs.

On the shrapnel shell and details a total of 128 manufacturing operations are required and 51 shop inspections. There are 65 gauges used, see Fig. 19, five sets being required for an output of 10 000 shells per day, or a total of 325 gauges.

In the manufacture of the cartridge case there are 50 manufacturing operations and 15 inspections. Seventeen gauges, Fig. 20, are required for one set, and approximately five sets are in use for an output of 10 000 per day, or a total of 85 gauges.

It might be said that even today, after one year on this work, gauges, fixtures and tools are constantly being subject to revision and simplification. These are matters which require time to develop and a national emergency should not be awaited before applying the necessary attention.

To enumerate the thousands of gauges that were required by the American manufacturers before the production of ammunition could be undertaken would sound like a fairy tale, the greatest difficulty being that none of the European Governments were able to furnish master gauges. All gauges and special tools that were prepared by the American manufacturers had to be made from

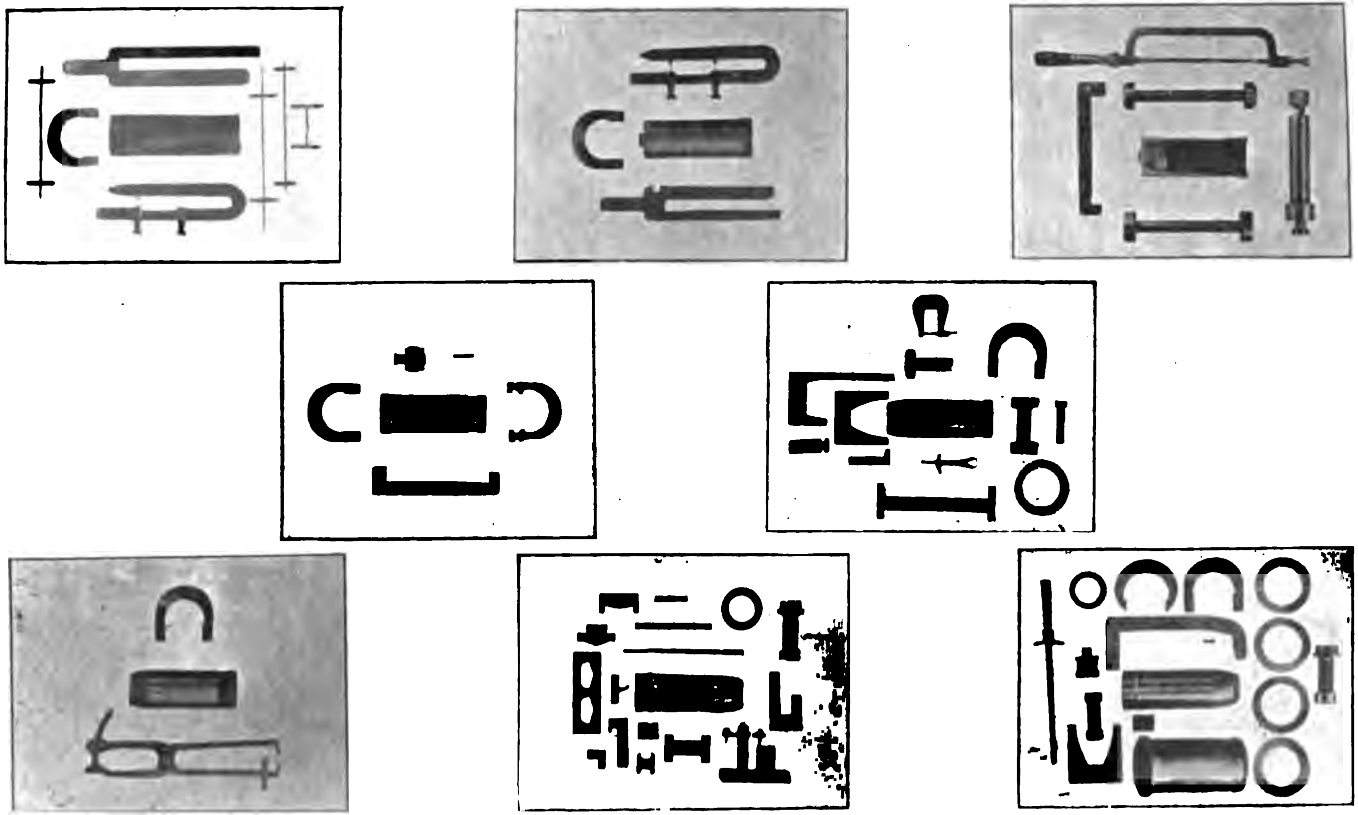

Fig. 19.—Sixty-five Gauges Required to Manufacture Shrapnel Shell.

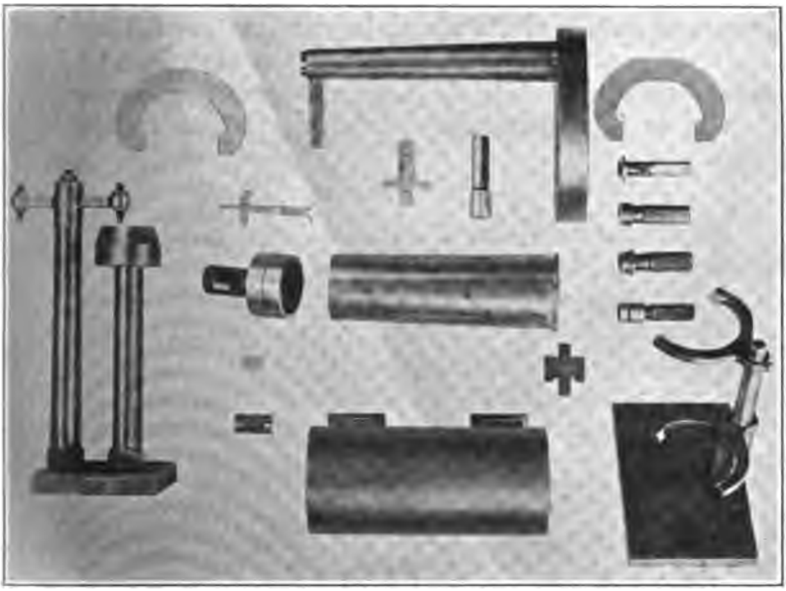

Fig. 20. Seventeen Gauges Required in Manufacture of Cartridge Cases.

Thus it will be seen that in plants where rifles, shrapnel and high explosives are being manufactured to the extent of from five to ten to twenty thousand per day, the number of gauges required is enormous, and, in starting this class of manufacturing, provides one of the greatest problems the manufacturers have to cope with.

INSPECTION

Undue stress cannot be placed on having a well-organized system of inspection to check not only at the end, but at each successive stage of manufacture, the chemical and physical properties of the product, as well as variations in size occasioned by the wear of tools, etc. An authoritative estimate reveals the significant fact that the total number of employes at the United States arsenals would not constitute a force of inspectors sufficient to care for the inspection of the product being manufactured by the combination of plants with which I am associated.

The personnel in the way of private, and Government inspectors as well, is of the utmost importance, for it is not wise to give the power of rejection to a group of uninformed inspectors who are lacking in judgment. And if power be not given to an inspection force it might as well be entirely dispensed with.

SPECIFICATIONS

Military supplies should, so far as practicable, conform to standards established by experts having a full comprehension of all the factors involved in the way of ballistics and commercial manufacturing as well. The plans and specifications of these materials should be submitted not only to the scrutiny of manufacturers, but also to that of the Consulting or Advisory Boards. They will thus be able to point out many modifications which would reduce the manufacturing cost and thereby speed up the

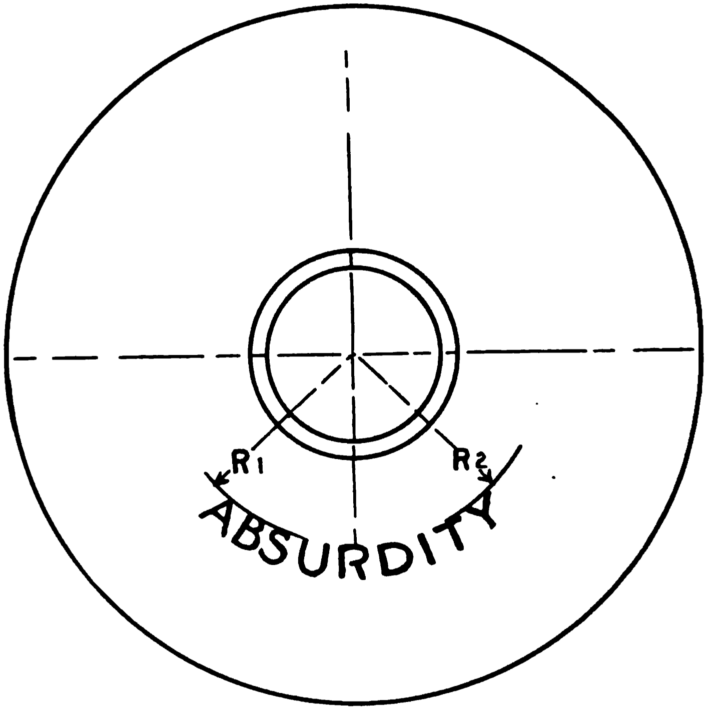

Fig. 21. An Example of Unreasonable Specifications.

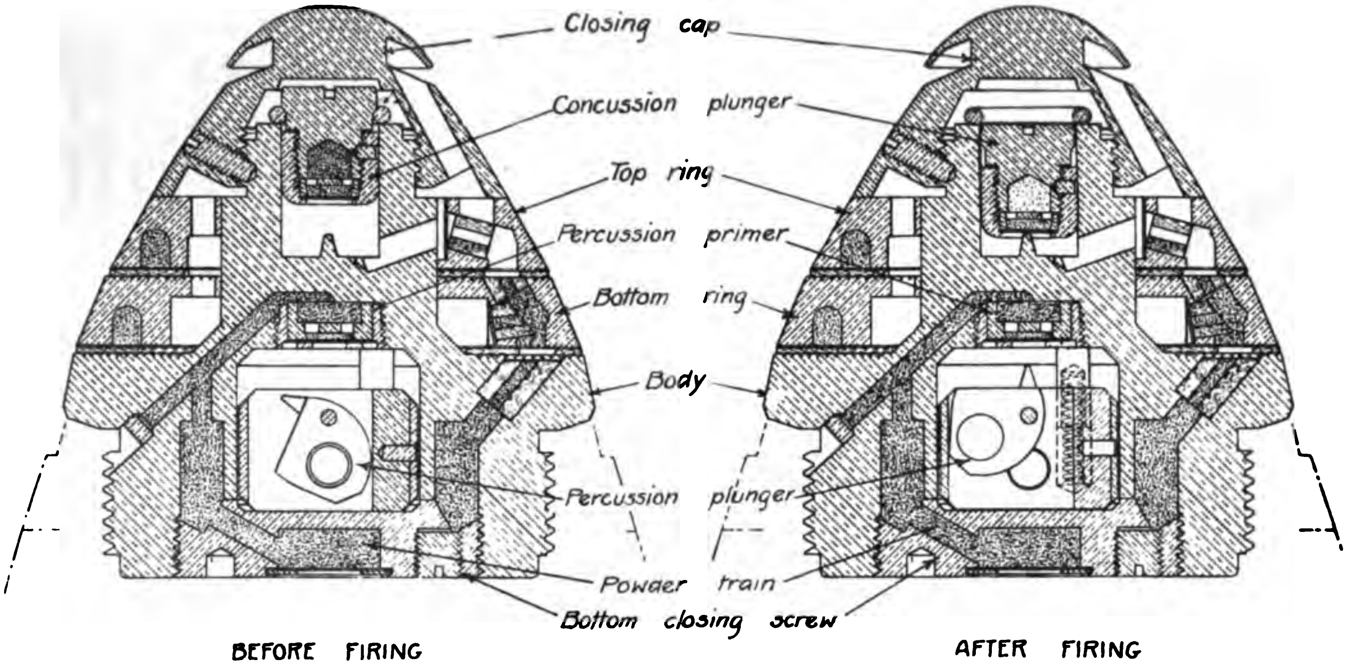

Fig. 22. British Combination Timing and Percussion Fuse.

output without materially affecting the military value of the product in the way of service on the firing line.

As an illustration of requirements utterly unreasonable I may, for the benefit of our own Government, speak of the rejection of 7000 cartridge cases for a defect in stenciling which happened at a local plant. The specifications called for the formation, by the stenciled letters, of a true circle concentric with the cartridge case ahead, as shown in Fig. 21. Due to one of the tools becoming slightly sprung the radius to one end of the stenciling exceeded the radius to the other end by about 1/32 inch. Sixty thousand cases had already been accepted and shipped before this was discovered. Seven thousand finished cases awaiting shipment were rejected on this account alone. Though the specifications provided no latitude, the poor judgment was almost wholly that of the inspector in view of the opening left by the Government. As a rule, however, the Government inspectors with whom we have dealt—i. e., the British—have been thorough and business-like, and to their co-operation and assistance is due much of the success of our undertaking.

It is pertinent to say at this juncture that the contract jointly entered into by several concerns for the manufacture of munitions has dealt with several governments, and an opportunity has been afforded thereby for comparing specifications and for judging of the merit in some of the requirements. If this perfection were necessary for the proper functioning of the shell, no objection could be made to its being demanded.

MANUFACTURE OF THE TIMING FUSE

Let us now consider for a moment the British combination timing and percussion fuse. This is made up as shown in Fig. 22. When expelled with the shrapnel from the gun, because of its inertia the concussion plunger tends to be left behind, striking its primer on the sharp projection or firing pin at the bottom of its cylinder. This ignites the powder train, which is of a length varying in accordance with the setting of the graduated timing ring and requiring a corresponding time to burn down into the explosive charge contained in the bottom of the shrapnel shell, which in turn scatters the bullets with deadly effect. In case of faulty setting, exceeding the proper time, the fuse will upon impact explode the shrapnel by virtue of the auxiliary percussion parts. The percussion firing pin is held in a withdrawn position by means of two safety pins, in order that unduly rough handling may not cause a premature explosion. Upon being fired from the gun the rotation of the shell, due to engagement of the copper band with the rifling grooves, causes these safety pins to fly out of engagement, and centrifugal force likewise throws the firing pin up into the position shown on the right. Upon impact the percussion plunger is thrown forward, causing the firing pin to strike the primer and start the powder train by a direct route into the shrapnel, giving thereby an immediate explosion.

The following is an extract from the specifications governing the behavior of this fuse:

> "Five fuses from a lot (2000 in a lot) will be tested, in shrapnel shells, by firing them set at "0" from a gun with a muzzle velocity of 1500 to 1800 feet per second. The fuses should burst the shells at from 5 to 50 yards from the muzzle of the gun. Should there be a burst in the gun, the lot will be rejected. Should any fuse fail to act within 50 yards, second proof will be taken; should a similar failure occur in the second proof, or should there be more than one such failure at first proof, the lot will be rejected."

The time limits this test imposes are from eighty-three ten-thousandths (0.0083) to one-tenth (0.1) second, or a range of seventeen ten-thousandths (0.0017) of a second. This exceedingly small margin requires that most careful and scientific attention be given to dimensions, quality of metal, air conditioning of the plant to hold the moisture content of the powder within very narrow limits, etc., if successful manufacture on a large scale is to be possible. It also bespeaks ample latitude where such can be given, as there is plenty of the intricate with which to contend.

You may be interested to know that at our plant, which has almost completed a contract of 1 250 000 shrapnel shells, not a single lot has been rejected, and in only two cases were shells required for second proof to check the first.

LOADING THE TIMING FUSE

At this juncture it will not be amiss to recite in some detail the problems that have confronted us in loading time fuses.

The burning time of the fuse is governed by the accuracy of the parts, by the burning time of the powder in the rings, and by the time of igniting this powder. This powder, by the way, is pressed into the fuse grooves with a pressure of 68 000 pounds per square inch. The ignition of the powder is accomplished by the use of powder pellets, which must be uniform, because pellets of varying texture take different times to ignite, and may introduce at this point a variable in the operation of the fuse. The ignition of the pellet is accomplished by guncotton. The use of guncotton in the pellet may also introduce a variable. For example, if cotton is placed in the pellet too tight, it prevents firing from the primer and interferes with the ignition of the pellet.

The burning time of the powder can only be determined by loading fuses with the powder as it is received from the powder manufacturer. The powder comes in lots of 240 lbs. and each lot has a different burning time. Very few lots as they are received are correct for time. After determining the time of each lot it is necessary to blend the lots together, so as to give the correct time. The selection of the lots for blending is largely a matter of trial. If 21-second powder is desired the mixture of 20 and 22-second powder in equal lots will not ensure the 21-second result. It often happens that this mixture will give a result faster than the fastest of the components, or slower than the slowest.

As a general rule all materials entering into an assembly plant should be proved correct before coming to the plant. This is especially true of powder, and the powder manufacturers should be in a position to guarantee their product suitable for use before shipping. There is no reason why this should not be done except for the one of expense. The expense, however, would be less at the powder factory than at the fuse plant, and would avoid serious delays in making the fuses.

The standardization of a timing apparatus for burning fuses at rest would be of great help to the fuse manufacturers. The very best apparatus which could be obtained upon starting this work was so slow that it took 1½ hours to determine the time for 10 fuses; but since then we have developed a timing apparatus which will give this time in 5 minutes. This saving of time is of vital importance, as 1000 fuses are often fired in order to get the time of one shipment of powder and test out the blends before it is deemed safe to use it for regular production. Standard methods for blending meal powder should also be determined by the Government. It was found that 16 hours was required to blend powder by the tumbling barrel method, which we understood was the accepted way of doing this work, but by designing special machinery we were able to get a slightly better result in 15 minutes. This saving of time also proves of decided advantage in fuse plants.

In preparing powder it is found necessary to be very uniform in methods. Factory operations are scheduled three days ahead

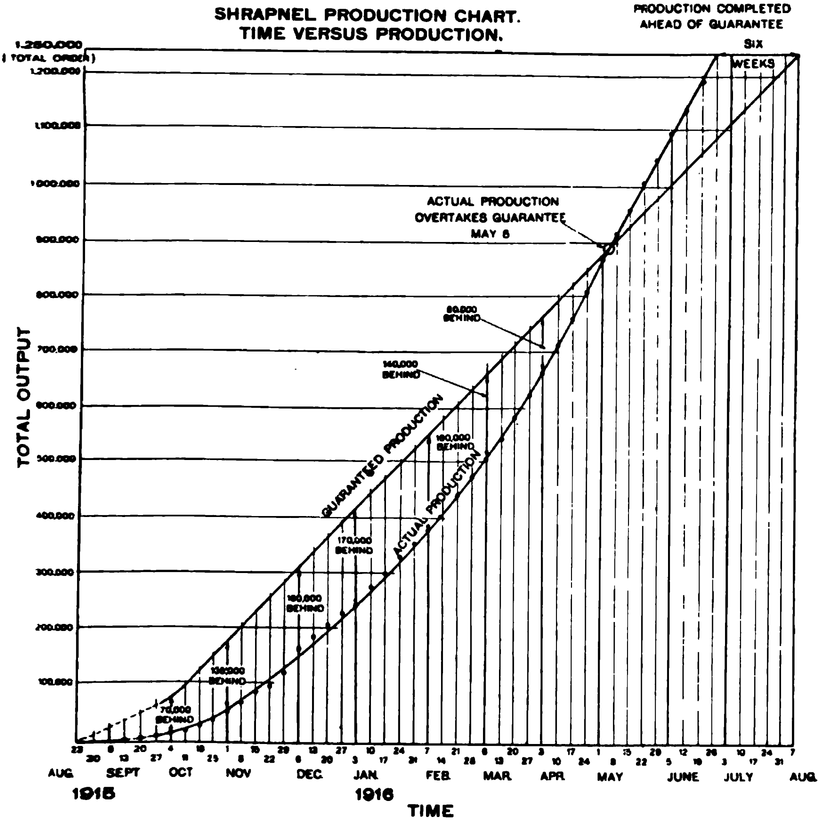

Fig. 23.

and powder is blended today which will be used day after tomorrow. After blending, the powder is spread on trays and put in the dry room for 24 hours. If operations are interrupted the attempt is not made to use powder that is left over from previous days, but the powder is used which has been prepared specially for the day on which it will be used. Powder, being hydroscopic, is blended and loaded under special air conditions—the blending rooms and loading rooms are maintained constantly at a temperature of 70 degrees and relative humidity of 45 degrees; the drying room is maintained at a temperature of 90 degrees and a relative humidity of 23 degrees.

UNIVERSAL TRAINING

Having sketched briefly the problem of industrial mobilization I wish to venture a word on the problem of personnel at the battle front—the consumer of the industrial output.

I am not a believer in militarism—God forbid it—but I do think that some form of universal training would not only make our country secure from aggression, but would result in increasing the physical, mental and moral fitness of the rising generation, besides inculcating in them the right kind of patriotism and proper regard for law and order, the natural result of which would be to do away with mob rule and riots now of such frequent occurrence.

We look upon militarism with abhorrence, as being inimical to free institutions. Moreover, the maintenance of a huge army would not be tolerated by a democracy, because we all know that in every problem of administration the most important element is the human element, and this knowledge must prompt us to stick to the democratic idea; for no manager of a political, commercial, industrial or transportation organization ever attained high ideals throughout his organization unless he thoroughly reckoned with the all-important human element. The commercial and industrial establishments of our country long ago recognized this truth, and the most successful business of today is the one conducted according to the rule of "square deal" and where a spirit of democracy pervades the administration. If this is true in the business world, it is applicable also to governmental institutions, and I know of no place where it would be of greater service to the nation than in the Army and Navy. Officers in these branches ought never to forget that they have been educated and trained as public guardians and that their superior knowledge and official position do not create within them the right of autocracy nor a license to treat with disrespect or contempt the private whose enlistment was actuated by patriotic motives. Managers of big institutions know that discipline and respect can be maintained without resorting to the tactics of a despot, and I predict that a large and loyal volunteer army will never be forthcoming in this country unless the officers of the Army and Navy also take cognizance of this fact and look upon the private not as a mere mechanical unit, but as a free-born American citizen to whom the nation owes a debt of gratitude.

I believe that every man should have the advantage of some military training during his high school, preparatory school and college life, that is, before he has settled down to make his own living and established a home. If this training is deferred it will be a financial hardship on a great many to temporarily abandon their regular employment for a course of training each year. In a large majority of cases there is a period between the termination of the school or college term and the assumption of family responsibilities where a young man could, without serious inconveniences, leave his employment for a given time each year to go to the training camp and rehearse what was taught him during his school days. Every boy has a right to be well born, and also has as much right to a military training as he has to a public school advantage or the right to spiritual worship. Military training will teach him how to defend his country in case of need and will also conduce to better health and stronger mentality, besides instilling in the boy that respect for discipline and system which makes for the best kind of citizenship.

In addition to universal military training of boys and industrial training of men it would seem that proper provision should be made for a considerable increase in the technical military training facilities of our country. All are agreed that while our shortage of men is serious, our lack of well-trained officers is even more serious. Where universal military training in a democracy seems to find small favor any scheme that will most conduce to the rapid training of volunteers in case of need is a preparedness measure of extreme importance. The development of a large body of carefully trained officers is a scheme more effective than any other for this purpose, I believe. I greatly favor the suggestion made some time ago that the Federal Government establish in various parts of the country schools where young Americans could receive free the kind of technical education now given at West Point. However, since we do not want to become a so-called "Military Power," the course in the proposed schools should be so modified that this technical training would turn out graduates equally capable for civil pursuits. On graduation these young officers would be assigned to commands, to practical military encampments or as instructors in public schools or colleges and there given the opportunity to apply their theoretical training. After that all but a chosen few could be turned back into civil life, subject to recall to training camps for brief periods each year or two, all the while keeping themselves thoroughly informed and up to date by following the developments in military science. History shows that the most successful American army officers were those that had experience of the kind just described. In case of war these thoroughly trained officers would be subject to immediate call, ready to assume charge. Each year these schools would, like other universities or institutions of learning, turn out thousands of men highly trained and fully equipped for profitable civil pursuits. Just that many thousands of young men unable to pay for college courses would be provided with proper education and the influence on national development would most assuredly be of the highest order.

Most of our great industrial establishments and a good many of our big railroad systems maintain schools for apprentices. These apprentices are usually poor boys who cannot afford to go to school after they have finished the eighth grade in our grammar schools, and whose education is supplemented by a thorough course of training under competent instructors furnished gratuitously by the manufacturers and railroad companies—a course of training that in three or four years puts them in line for almost any position in the organization. The fact that these boys are willing to work for a mere pittance during three or four years in order to supplement their common school education shows that they are made of the right kind of American stuff and would furnish ideal material for the military schools I have just described.

TRANSPORTATION SYSTEMS THE CONNECTING LINK BETWEEN FACTORIES AND BATTLE FRONT

The word "mobilization" means inherently "a rendering movable;" "assembling;" "putting into movement." This immediately directs attention to our transportation industry, the greatest of all industries with the possible exception of agriculture. It is the connecting link between the raw product and the tools for making it available, between the raw product and the factory, between the factory and the battle front. It needs no argument to prove that one of the greatest mobilization problems is that of providing adequate transportation facilities. Of what utility is an army without supplies, of guns without ammunition, of bodies of men and material unless they can move quickly from place to place in either defense or offense. Better, in fact, that we had neither armies nor supplies nor factories nor foodstuffs than to have all these things in abundance without that dominating, interlinking, all-important factor—*transportation.* And no factor in the whole broad range of a national preparedness program is more fundamental than the adequate correlation, standardization and development of transportation to the utmost efficiency and usefulness.

With an area of over three million square miles, and resources abounding over practically every square mile, we have a country of "magnificent distances," so that transportation becomes doubly important, or even we might say with the mathematicians —the value of transportation facilities increases as the *square* of the distance resources must be moved to when they are needed. In most of the civilized countries such as England, Germany, France, Italy, Austria, etc., the territory is relatively much smaller and the average railroad hauls much shorter than here. We must realize, therefore, that enormous as our resources are they are only resources *actually* as they are made available quickly and in large volume through adequate, well-organized and perfectly operating transportation facilities.

It would, therefore, seem that an Advisory Transportation Board, to work in conjunction with the military and naval officers and their Advisory Boards, is an indispensable adjunct to the preparedness scheme, and to my mind there is no more important item to be worked out in connection with the entire preparedness proposition than that of transportation. It is a well-recognized fact that the United States possesses the greatest transportation facilities in the world. To operate these wonderful arteries of transportation requires brains and skill second to none in the world. The Advisory Board should, therefore, be composed of the biggest railroad men of the country, who I feel sure would be broad enough and patriotic enough to serve without compensation.

CONCLUSION

Effective mobilization of our industrial resources must be based upon organization and intelligent leadership. These factors in industrial progress are gradually being recognized and put well to the front, as is evidenced by the movement for the conservation of our vast resources and by the more rational and liberal attitude toward big business on the part of the thinking public and their representatives in legislative assemblies which heretofore have retarded rather than fostered industrial progress.

The war in Europe had been under way for more than a year before some of the belligerent countries were able to equip the men who voluntarily offered their services. The governments put forth their very best efforts, yet the mobilization of their industries lagged, due to lack of foresight. This lesson is certainly an impressive one and we should not fail to take it to heart.

I remember reading shortly after the close of the Spanish War a statement made by Lyman J. Gage, then Secretary of the Treasury, that there were three things in warfare that were absolutely essential, namely, money, MONEY and MONEY. A greater truth had never been uttered, and I believe that the statement will apply to modern conditions with equal force. The present European conflict has taught us, however, that in addition to the requirements enumerated by Secretary Gage, there must be the all-important item of preparedness. Had England been one-tenth as well prepared on land as she was on sea this war, according to the best military experts, would have been of much shorter duration. Like ourselves, England trusted to her resources, and when the fatal blow came she had to pay dearly in life and property for what could have been well provided for in times of peace. Her experiences taught her and, if we are wise enough to heed them, will teach us that modern warfare demands the closest co-operation of all economic elements in a nation, and, moreover, that the people must be brought to realize, by means of a just, efficient and successful Government, that they have a country and national institutions worth fighting for and making sacrifices for, such as have been made so readily by Germany, to whom all of us are wont to look for lessons when the game of war is under discussion. The United States in its present condition can hardly be regarded as a cohesive nation. We are much too inclined to be selfish, and unless we learn to subordinate our individual selfishness to a general recognition of broad public rights and needs, we cannot hope for the most effective co-operation in case we have the bitter misfortune of becoming involved in war.

As a nation we are yet young and childish, and immature in many of our judgments. We are self-confident and physically exuberant and strong. We look back upon our brief history with eyes and minds that tend to enlarge upon our national accomplishments. We have not looked forward enough to realize that war is no longer a question of men or resources, or even money; but of a vast complex system of organization, shops and mills, and every industry, of all skilled labor, of all executive intelligence, of all financial foresight and acumen; in short, of ability to make use, and effective use, of these resources and in the minimum of time.

But a great process of education is now in progress. Europe is teaching us graphically—by moving pictures, as it were—what war in all its phases means today, and how ill-prepared we are to meet any such terrible stress. Of what use, indeed, are millions of men if they are untrained and uninstructed; of what use are guns on land or sea if we have not enough qualified machine shop capacity in the whole United States, as at the present time, to supply ammunition; of what use are foodstuffs and clothing and supplies of all kinds if they cannot be purchased and delivered quickly to the armies and navies which need them; of what use is vast national wealth if it cannot be used systematically and in order for things needful; of what use are great transportation systems without adequate rolling stock or terminal facilities, or centralized executive direction? We are like the sailor in a small boat in mid-ocean surrounded by miles of water and not a drop to drink. We are like the traveler in the desert who sees all the glory of the mirage and does not realize that it is only a picture of what might be.

The engineers of the country may well lead in the new idea of national pride and greatness; that every man is a citizen for *service* to his country, be that service hard or easy as it may. Let us teach thrift as the French have learned it, and economy in natural resources. Let us strive for efficiency as Germany has attained it in the useful arts and sciences. Let us teach the dignity of Labor, the rights of Capital (accumulated savings), and the folly of internal contentions and struggles which only waste and weaken. Let us teach intelligence and sound judgment to all the people, and quickly will the nation realize that great resources do not necessarily mean strength, but only when the whole process of bringing these resources to utility quickly has been evolved.

SCIENTIFIC METHODS IN CONSTRUCTION

By SANFORD E. THOMPSON* and WILLIAM O. LICHTNER*

The tendency in construction is toward more systematic methods of management. We see this in better plant layout, in the adoption of machinery, in progress charts, in more accurate cost keeping. All of these things indicate that the construction man is following the trend of modern progress and paying more attention to the details of systematic management.

This, you will say, is common sense; it is simply the desire to reduce costs and to study conditions so as to make the work run smoother. As a matter of fact, however, the determination of best ways of handling work, not by mere opinion or judgment, but by a comparison of different methods, study of complete records, and allowance for the variations which occur, really tends toward the scientific method. A carefully planned layout is the result of comparing records of experience with other plants, a consideration of all the variables, and the selection of certain features which experience has indicated to be the best standards. In selecting special machinery, the elements of the work have to be considered, the operation of the individual parts, the capacity, the idle time, the initial cost, the repairs, the running expenses, and the depreciation. As a matter of fact, such studies are apt to be valuable in proportion to the thoroughness with which they are pursued.

In this paper it is proposed to consider the application of modern methods of management to engineering construction. To make this clear, the development in manufacturing processes will be discussed along with the application to construction methods. Finally, illustrations will be given of the actual handling of several types of construction work by scientific methods.

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RESULTS OF SCIENTIFIC MANAGEMENT IN MANUFACTURING

That scientific methods are advantageous in shop management is now generally recognized. Nearly all of the younger managers are introducing, either on their own account or with the aid of outside advice, various features which are distinctively scientific management methods. While but few have carried to perfection the plan as evolved by the late Frederick W. Taylor, many of them are obtaining results which have increased output, reduced costs, and increased wages.

RESULTS OF SCIENTIFIC MANAGEMENT IN CONSTRUCTION

Construction managers have been slower than shop managers to introduce the various features of modern methods which apply to the handling of the employees. A few cases which have come under our direct observation have shown the following results:

Operation	*Percent Reduction in Cost*
Trench excavation	32%
Backfilling	87%
Pipe laying	59%
Form construction	30%
Form erection	33%
Bending and placing reinforcement	35%
Framing in house construction	14 to 44%*
Floor laying	36%

*Depending on character of work.

These represent actual figures. In certain of the items an allowance must be made for somewhat increased clerical work, but the saving in cost still remains large. Along with this actual cost reduction comes the increase in output with the same men (a very important feature with the present scarcity of labor), increase in pay to the workmen, and greater smoothness of operation.

You may ask, if such results are obtainable, why it is that everybody does not do it in this way? Before I complete my paper you will realize that the development requires so much thorough study, investigation, and really scientific treatment, that comparatively few manufacturers and still fewer construction managers are yet ready to take up the matter in the detailed fashion necessary to get the best results.

POSSIBILITIES IN MUNICIPAL WORK

The possibilities of reducing costs in municipal management of construction and maintenance problems through the introduction of scientific management has been given scarcely a thought. Some indications of results that might be expected in this line are shown by the work done in the street cleaning department of the city of Chicago during a previous administration. In Philadelphia also, under the administration of Mr. Blankenburg, real progress was made along these lines. The tendency at the present time in theory, and in a few cases in practice, is toward the elimination of politics from the management of city work. When our city work is planned ahead and decisions as to the character and location of jobs to be done are made, not by haphazard opinion, but by thorough study of the situation and definite records, we can reduce the work in a city to a basis from which results can be expected from the standpoint of both quality and cost that are at least on a par with work done by contract. Standards once established will form permanent records which it will be difficult even for changing administrations to overturn. There is no reason, furthermore, why such standards should not be based on a fair day's work with a fair day's pay, and the management organized in such a way as to maintain the standards.

FUNDAMENTAL PRINCIPLES OF SCIENTIFIC MANAGEMENT

The fundamental principles of scientific management lie in (*1*) the adoption of standard methods for labor performance and (*2*) the control of these methods in practice. The science of management determines, after thorough study and thorough investigation, the best way of performing each individual operation; the sequence of operations; the implements and tools which give the best results; the proper materials to use under different conditions; the quantities of materials required for a given quantity of product or for a special lot; the quality that must be maintained; and, where time is involved, the proper time to perform each operation.

Even from so brief a statement as this the breadth of the scheme and its far-reaching influence upon the vital features of management are evident. To attain such results as these requires time and patience, and a thorough appreciation of the ultimate good that will be attained. A definite system of planning is necessary to carry out the methods after establishing them.

THE DEVELOPMENT OF SCIENTIFIC MANAGEMENT

The development of scientific methods of management, and by this I mean the attainment of the results just indicated, necessitates development along certain distinct and well-defined lines. Scientific management requires:

Standard methods of performing each operation.

Standard machinery, tools and equipment.

Classification of materials.

Plan for handling and distributing materials.

Plan for distributing work to the employees.

System for training workers to do each job in the best way.

Standard times in which each operation should be performed.

Standards of quality and a system for maintaining this quality.

Methods for recording the time taken and the amount of work done.

Arrangements for paying the men in accordance with their individual accomplishments.

These features are being adopted by the more efficient manufacturers and to a limited degree by construction managers. As illustrating the necessity for further development along these lines, we may take them up more in detail, considering the application both to industrial and construction operations.

Standard Methods of Doing Work: Construction men often assume that in manufacturing processes the methods of operation are standardized, and that the work usually is repetitive. The materials and product may vary to a certain degree, but the general scheme is the same, the machinery is not subject to change, and one would think that methods would be established so as to permit of scarcely any variation. Now, except in the case of automatic machines, this is true only in a very general way. Just as soon as the details of the processes are examined, and we get down into the methods of handling the materials, of giving out the work, of performing various motions incident to the work, we find, except in shops operating under scientific methods, so great a variety in practice as to bring the work into a "rule of thumb" class. I may illustrate this by an example from practice. Let us take the case of a machine for cutting paper.

The cutting of paper as required in a printing establishment or in the finishing department of a paper mill seemingly is a very simple operation. The machine consists essentially of a table with a slot through which a long knife passes up and down at the will of the operative. The operation consists of taking, in several lifts, the sheets of paper from a truck, placing these on the cutting table until a thickness of about four inches is reached, cutting, turning the paper if more than one cut is needed, and placing the cut paper back on to another truck.

Very simple it is—placing the paper, cutting and removing. But what do we find when we begin to make studies on the operation for the purpose of laying out—not a piece rate fixed by guess—but a definite task adapted to the capacity of the machine and the operative.

We find at once, when considering simply the very first operation of lifting on to the machine, that the time is affected by the number of sheets taken to a lift. Study shows that the lift which a man can take is dependent upon the thickness of the paper, the size of the paper, the coating on the paper, and the way it is handled.

Before definite times can be fixed even for so simple an operation as cutting paper, a scientific investigation combined with the time study is necessary to allow for each one of these variables, and to find just how the sheets should be handled under all possible conditions. We find that to keep the machine running to the best advantage; to cut one job in its entirety so as to avoid frequent setting of the machine; to arrange the count so as to know the amount run through; a definite scheme of planning and routing of the paper and moving it to and from the machine is absolutely necessary.

In connection with the scientific study and with the arrangement of the routing, but especially for the purpose of determining how much of each grade, size and weight should be handled in a given time, study of standard unit times for handling, cutting, turning, etc., must be made. But having established the time for the job, having routed the materials in proper fashion, the work cannot be put through on time and of the required quality unless the operatives are instructed how much of each grade and size of paper to take at a lift, the thickness that can be cut in each case, the quickest way to manipulate the machines, and so on.

In construction many of the operations are much simpler than in manufacturing propositions. However, we find the same lack of standards as in manufacturing plants.

We may take, for example, so simple an operation as trenching in construction work and run up against the same necessity for the establishment of standard methods and of a proper system for handling them as we do in the cutting of paper in a shop. Suppose that it is desired to put a job of trenching on to either a piece-work or a task-work basis. Just as soon as we take hold of the problem we run up against the difficulties in the character of the earth. We wish to determine, for instance, the time which should be taken to excavate a certain section of trench and the time to backfill it. We find the labor of doing this, and therefore the time, varies with the character of the earth, the amount of picking, the nature of the picking, the water, if any, the amount of sheeting required, the staging, the arrangement of benches, the arrangement of the backfill, and so on. When all these matters have been considered and the men trained to do the work in a definite fashion, then can be taken up the question of distribution of the tasks and the method of routing to handle these tasks. On the face of it, to the construction man used to rough work, this appears too complicated even to consider. To go into details cannot be done within the limits of this paper, but it may simply be said that the work has been handled in this way and handled successfully, with a large reduction in cost both in excavation and backfilling.

Similar illustrations might be taken from the more complicated processes of construction. Take, for example, the process of form construction for reinforced concrete. In the manner of erecting the forms we find scarcely two contractors who adopt the same methods; we find scarcely two superintendents for the same contractor who follow the same plan; we find the men on the job left in a measure to their own sweet will as to just how they shall do the work. Even in the making of forms, which is essentially a manufacturing process, it is customary to let the carpenter pick out his own lumber, select widths and lengths for a certain form, and frequently even to make the details of the design to suit himself. Later in the paper this will be considered in a more constructive fashion to show how such things can be done by what are more truly scientific methods.

Standard Machinery and Implements: In connection with tools, machinery and implements, it is frequently advisable and, in fact, absolutely necessary in order to obtain the best results, to make special tests, sometimes very extended tests. More has been done along these lines in both construction and manufacturing than in many of the other features we are discussing. In many cases, both in construction and manufacturing, we have standard machines which have attained a very high degree of perfection. As yet, however, this is true only in a limited number of cases. As a general rule, when one is ready to lay out the work for an operative so as to get strictly uniform results, when one is prepared to get out the maximum output feasible for a machine, certain changes must be made. In almost every case the method of operation and the speed must be altered to produce the most economical results.

Turning to construction work, how many of us have made any really scientific comparison of the different types of concrete mixer, either as regards the resulting concrete or as regards the economy of operation, freedom from repairs, and life? How many of us know the size of shovel that should be used for different kinds of work, or the shape of shovel? How many of you can tell whether a long-handled or a short-handled shovel is most economical, and if sometimes one is best and sometimes the other? What are the conditions which should govern the selection:—the character of the earth? the depth of the excavation? the height of the man? the physique of the man? the wetness of the ground? or the combination of several of these items?

These simple matters illustrate how little we engineers go into the details that, in many cases, are really vital to the attainment of economical construction and profit on the job; and how far short of ultimate economy are the contractor's methods. For example, we found recently that a man shoveling sand to a height of 12 feet required 40 percent more time with a long shovel than to shovel the same quantity with a short shovel. In a trench, however, where the workman is cramped for room it is economical to change at a certain depth from the short to the long-handled shovel.

Similar illustrations could be taken for almost any class of tools, implements and machinery.

Standard Materials: In construction fewer materials are used than even in a manufacturing establishment where the product is varied. The advance in certain directions in construction has been more marked than in manufacturing. Many of our construction materials are covered by standard specifications which are used in letting work. There is opportunity, however, for considerable further developments even here.

Distribution of Material: In any manufacturing plant run under the ordinary methods of management, where either the process is complicated or the product is made up of a combination of parts, there is frequent cause for complaints in the various departments and among the operatives from delays in obtaining materials. Talking with a manufacturer only a few days ago where they are introducing improved methods, he told of case after case where formerly the materials would go to the operative with one part missing. The lot would then have to be laid aside, to be taken up perhaps a day or two later after the missing part was supplied. On the face of it, it would seem that such complications should be corrected at once. However, when one sees the complications incident to many manufacturing processes, it is evident that this is no easy matter and requires for the elimination of such defects the introduction of a very complete system of routing.

In construction, the processes are simpler and the delays are of a different kind. Here we find, frequently, long waits and shutdowns through errors of the purchasing department or the forgetfulness of the foreman to supply materials to start or prosecute the work as scheduled. Again, a sub-contractor may not have been notified to begin work or properly followed to see that his part of the work is done. Again, we find delays due to poor delivery of materials, sometimes unavoidable, but frequently to be overcome by proper system.

How often on a bricklaying job do we hear the calls of "Mort!" "Mort!" how often do we find the bricklayers slowing up because the brick or mortar is not given to them fast enough; how often do we find the quantities of the different kinds of brick delivered not corresponding with the wall being built.

Now, while we do not wish to convey the idea that on all types of construction it is possible to plan out in advance the details of every feature, it may be said with scarcely a qualification that there is not a single construction job where the smoothness of operation cannot be improved, the different parts of the work made to fit into each other more exactly, and the work laid out and distributed to the men in more economical fashion, by adopting methods along the lines of scientific management.

Distribution of Work: A superficial examination of almost any shop which is not markedly ill managed shows on the face a smoothness of running and an even flow of work. However, as we make a more accurate study of the operations, and especially when we talk with the subordinates in the management who handle the details, or again, if we talk with the employees, we find, almost invariably, frequent cases, occurring not merely weekly or even daily, but constantly during a day's work, of delay in distribing the work and laying out jobs for the employees.

On piece work this reacts against the employees and reduces their day's pay. In day work the output is reduced and the cost increased. Where machinery is involved, the poor results of the distribution or routing are particularly serious, because the machine cost must be added to the direct labor, consequently the loss may be at least doubled.

On construction work we have similar conditions, frequently, in fact, much worse than in shop work. Men are called from one job to another at the caprice of the foreman or superintendent, simply because he forgot to plan out certain jobs which had to be done and neglected to study the proper sequence of work or see that preparation was made in advance for each job.

This is by no means a criticism of the foreman, for the foreman or superintendent usually has so many duties to attend to that it is a physical impossibility to handle all the features with the maximum smoothness and efficiency. It is a criticism of the method of handling the work and the very fact that all the planning and distribution of the work is left to the foreman instead of providing a special plan for handling it. The *planning* should be *separated* from the *execution.*

The arrangement of a gang in construction is frequently a complicated piece of work, especially as it is commonly handled—by judgment alone. The balancing of picks to shovels, of barrows to shovelers, of carts to loaders and dump men, is no simple problem. The value of proper arrangement is appreciated by the contractor more than by the engineer. In a recent civil service examination for a $3000 engineering position (in which one of the authors assisted) scarcely one applicant out of the thirty appreciated the principle that on a job using teams it was necessary to balance up the time of the shoveling gang with the time of the teams going to and from the dump.

Instruction and Training: The necessity for instruction and training of the operative is evident just as soon as we begin to go into a detail study of an operation. Yet, even in the factory, the principles are likely to be but little observed. Too often the fact that a job has been "always done" in a certain way furnishes the plan instead of finding out just what is the best way of doing the work. Too often the method of handling a job is left entirely to the operative. One man does a certain thing one way, another does it another way, using perhaps twice the exertion and requiring twice the time as the first. Now, there is one best way, and by training this best way can be adopted.

The necessity for proper planning and instruction is particularly noticeable in machine shop work. Formerly, and even at the present time, in many shops not simply the method of doing a piece of work on the machine tool is left to the judgment of the operator, but he is supposed to regulate the speed and feed of the machine, to select the kind of tool, and to exercise his personal opinion, or rather guess, on all the points which come up.

In a machine shop scientifically managed, instruction cards describe the work in detail.

This lack of training and instruction on construction work is more noticeable than most of us realize. A shovel, for example, should be held and operated in a certain way. The laying of a brick as ordinarily practiced takes many more motions than are required to do the job properly. The location of the brick and mortar is left to the tender or bricklayer, without regard to whether or not it is being done in the easiest way. In such machine work as bucket excavation, scarcely any attention is given to the arrangement of the buckets so as to utilize the machine to the best advantage.

In shoveling, the selection of the shovel, and the kind of pick, and the method of working them, is made simply by the judgment of the foreman or, more frequently, by the laborer himself. One laborer will pick his material in such a way as to reduce his labor of shoveling by about half; another will scratch the surface with the pick, and increase the amount of work he is doing and decrease the output by wrong methods. No distinction is made between methods of handling different kinds of earth.

These comparisons might be extended indefinitely. We might refer in the same way to the carpenter and the selection of his tools; the way he handles the materials to be worked, and so on.

These may seem small details, but it is the details which make up the whole. It is the loss of minutes in a day which increases the cost of the job. It is the extra exertion on certain things, and the bother, which tire a man in his day's work.

Maintenance of Quality in Workmanship: It is an old-fashioned idea that quality cannot be maintained if the work is on piece work or task and bonus. On the contrary, quality can be not only maintained, but improved. The reason for this is simply that with the proper methods a poor quality of work means a loss to the worker through a lower day wage or lower rate per piece, or the loss of bonus. Furthermore, the standardization of material and the system of inspection makes it easier to keep track of the quality.

Standard Times: In shops piece work of course is largely employed; in construction but very little. You will perhaps say that "piece work can be carried on in shops, but it cannot be carried on on the construction job; our materials are too varied; our men are changing from day to day and from job to job; our work has too much variety." In certain cases this is true and certain types of construction work cannot be handled satisfactorily on piece work or any modification of it.

The real difficulty, however, does not lie so much in these objections as it does in the fact that we do not study the conditions·and go into the details as we might. We find the same trouble in manufacturing. The employees usually have a certain system of their own which glosses over the inequalities of the ordinary piece rates. For example, in the ordinary shop under old-fashioned management, a girl may be given a number of jobs of different lengths in a day; each to be done on piece work. By a system of figuring which only the operative knows she is able to adjust these varied rates and pieces of work, although they may be very different, and yet earn each week the amount which the girls in that department know can be earned without cutting of rates.

Frequently the girl or the man who is distributing the work to the operatives has to distribute it so as to give the workers a fair deal. Talking very recently with a girl who distributed such work, she told us that she had to satisfy the girls and give them a square deal by changing first from jobs where they could hardly make a fair day's pay to jobs with "velvet," as they are called.

I have in mind another case of paper cutting where the variation in the character of the work ranged from simply trimming the edges of large sheets down to the cutting of sheets into pieces as small as one inch square. The planning out of accurate times for each job, for there were scarcely two jobs alike, seemed on the face of it a physical impossibility. The former piece rates were many of them 50 percent too high, while others were 50 percent too low. Yet, by thorough analysis and time study, it was found possible to determine exact times for each piece of work. Each part of the operation, such as lifting, jogging, running gauge, trimming, etc., had to be studied in detail and standard methods fixed for each little division of the work and standard unit times—some of them averaging not more than three or four-hundredths of a minute in length—had to be determined. As a result of this standardization, and also in a measure through the reducing of the tasks to a uniformity in the amount of labor required, the output was more than doubled, the machine costs reduced nearly 50 percent, the labor costs reduced 25 percent; while at the same time the wages paid showed an average increase of 33 percent.

In scientific management the variation in jobs is provided for by thorough analysis of the operation and adjusting the various conditions so that piece rates may be made up which provide for the variables, or else definite task times may be set for the operations under different conditions. We have referred already in connection with the cutting of paper to the general plan adopted. In a few minutes we will illustrate more in detail how analytical methods have been carried out in construction.

Paying the Men: In any form of management, in order to obtain the best results from labor, it is necessary to reward individual efforts, to provide an incentive to do a good day's work, to provide, where possible, an incentive to rise from one position to a higher one. Whether the form of payment shall be on a piecework basis, on task and bonus, or on premium, depends upon the conditions. In most cases, however, it has been found that the task and bonus plan, which involves the laying out of a definite amount of work to be done in a specified time and paying a bonus for accomplishment, is the best. This has been shown to be satisfactory in such construction work as form making, house carpentry, bricklaying, earthwork, and the placing of steel.

COST ESTIMATES

The difficulty in estimating accurately the cost of labor in contract or city work is recognized by all who are engaged in this problem. In a recent paper* before the American Concrete Institute attention is called particularly to the necessity for more accurate estimates and the possibilities of utilizing unit times and costs to a much greater degree than at present. The variation in bids received from different contractors is shown by an inspection of any of the current engineering periodicals. Opening one of these at random, we find the four bids on a certain job to be

*"Unit Costs in Construction," by Sanford E. Thompson, summarized in Engineering Record, Feb. 26, 1916, p. 277.

$117 000; $126 000; $143 000; $171 000. This does not represent an exceptional case, but is the general rule on work where the cost of labor is relatively large.

It must be the aim not simply to know how to do the work cheaply, but to figure estimates more accurately, at the same time taking care to keep the cost of the figuring as low as possible. It is useless to get a job at a low figure and lose money on it. It is evident, further, that having made the bid with care, the construction must be handled in such a way as to come within the limit set. This requires not simply a fair comparison with the monthly estimates, but the follow-up from day to day of quantities and wages so as to have a running check on the work. It takes but little more time in figuring an estimate where material costs are estimated in detail to go also into unit costs of labor. This, of course, is not simply a mathematical proposition, but requires a knowledge, based on first-hand experience, of actual costs, or else on records where conditions are stated in full.

An example of inaccurate estimating is found in estimating the cost of forms in reinforced concrete construction. Three methods of figuring are used which give results at total variance with each other. Take, for instance, the figuring of the cost of labor on column forms. This is sometimes figured by the cubic yard, sometimes by the square foot of contact surface area, and sometimes by the cost per 1000 ft. B. M. Both the cost per cubic yard and the cost per square foot give results which are inaccurate when applied to different sizes of columns. To illustrate we may compare the costs, based on accurate unit averages and checked by work on various jobs, of a 15 in. and a 24 in. column in a building of 12-foot story height, all other conditions being the same:

The cost per member as computed from a table in "Concrete Costs"† for a 24 in. column form is $8.00, and for a 15 in. form, $6.74. Figuring this in terms per square foot contact surface area we find it amounts to $0.083 for the 24 in. form against $0.105 for the 15 in. form. Ordinarily a contractor figures the same unit price, which would mean that his price on a 15 in. form would be 27 percent too low. If figured as cost per cubic yard on he same basis, the cost of the 15 in. form is actually 115 percent nore per cubic yard of concrete than that of the 24 in. form, and f estimates are made in the two cases on the same unit price hey will be incorrect to this extent.

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†By Taylor and Thompson, 1st Edition, p. 631.

You may say that this is an extreme case, but we are quoting lmost exactly from an actual case of a contractor of large experience in building construction, but with limited experience in reinforced concrete construction, who used, not the square-foot method, but the cubic yard method of estimating in two buildings with heavy and light load. Fortunately for him, he built the heavy building first, and so simply lost the job on the second building by figuring way up in the air.

To illustrate the variations in labor costs of different members in form construction, the table below presents a few values selected from "Concrete Costs:"‡

UNIT COSTS IN CONSTRUCTION

Labor Costs of Forms for Columns, Beams, Girders and Slabs

Costs include 10 percent for foreman and 15 percent for superintendence, contingencies, etc., but do not include profit or home office expense. Carpenter labor, 50c per hour; ordinary labor, 25c per hour. Material, 1-inch lumber.

Size Inches	Make Form $	Place and Remove Form 1st Time $	Place and Remove Form After 1st Time $	Remake Place and Remove Form $
12-Foot Columns—Labor Cost per Member Iron Clamps				
8 by 8	1.16	4.68	3.77	5.53
16 by 16	1.46	5.45	4.40	6.16
24 by 24	1.80	6.20	5.14	6.86
36 by 36	2.61	7.64	6.33	8.14

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‡This table is taken from the American Concrete Institute paper referred to, the data being derived from the complete tables in "Concrete Costs," 1st Edition, pp. 633 to 654.

20-Foot Beams—Labor Cost per Member
Size Measured Below Slab

4 by 8	0.92	2.42	1.97	2.79
6 by 12	1.09	2.75	2.31	3.23
8 by 16	1.26	2.99	2.59	3.64
12 by 24	1.75	3.41	3.09	4.29

20-Foot Girders—Labor Cost per Member
One Intersecting Beam

8 by 16	1.38	3.27	2.75	4.31
12 by 24	1.82	3.86	3.20	5.02

Labor Cost of Slab Forms* per 100 Square Feet
of Slab Surface

	0.81	2.53	1.90	2.06

*Based on slab units built two panels per bay.

For inexperienced builders, increase cost 33 1/3 percent.

For special design, add 10 to 50 percent to "Make Forms."

If no mill saw on job, add 50 percent to "Make Forms."

If old lumber is used, add 75 to 100 percent to "Make Forms."

For rectangular columns, select values for square columns having the larger dimension of the rectangle.

For wall columns, add 50 percent to all except "Make Forms."

The possibility of accuracy in estimating by methods of unit costs is indicated by such studies as these. For the purpose of estimating only, a contractor cannot afford to get the details required for such information unless they are obtained in connection with his own practical work in managing his varied contracts and utilizing the results in connection with the organization of the work on the various jobs.

PRACTICAL APPLICATION OF SCIENTIFIC METHODS OF CONSTRUCTION

To illustrate the possibilities in construction we will take up two or three types of work where excellent results have been attained.

The aim of scientific management is to find the best and cheapest way of accomplishing a piece of work and then providing means for doing it in this fashion. The details of the methods to accomplish this are discussed more fully in a paper on "Construction Management"* by the writers, to which reference can be made. Certain general principles are outlined below.

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*Journal Western Society of Engineers, Vol. XXI, No. 2, Feb., 1915.

FORM MAKING

One of the types of construction which offers an excellent opportunity for saving in material and labor costs is form construction in reinforced concrete. This is really a shop job. The essentials, as in shop work, are to:—plan in advance; determine the best method to employ; lay out the work; train the men; and provide an incentive to the men for carrying out the work as required of them.

Forms Plans: It has been found convenient and economical to draw up each member of a form so that all details can be worked out in the office, leaving nothing for the carpenter foreman and carpenters to do but to construct the forms according to blueprints. The schedule of lumber will show on each drawing, so that an accurate lumber list can be drawn off very quickly and thus prevent ordering a lot of dimensions which require more time to handle and put through the saws to get the correct size. A big saving will result in labor and material from the fact that the drawing will show, for instance, that a form can be made from three 6-inch boards and one 8-inch width, while if left to the carpenter he would probably use five 6-inch boards and rip off a 4-inch strip to be perhaps broken and thrown in the waste pile. The saving in labor is the time ripping one board and the time handling one extra board. The lumber sawed would be the 4-inch strip, or actually 15 percent.

Ordering Materials: One of the largest savings in cost from scientific methods in such work as form making is in the material. By advance and systematic layout exact quantities are obtained. In certain cases it is possible to order material to length and width in advance. Furthermore, the time of delivery can be planned and frequently delays on this account avoided.

Plant Layout and Routing of Lumber: In starting a job it is necessary to lay out on paper exactly what is to occur in actual practice. This means laying out the location of the machinery and materials. The greater refinement to which one can go if space is available close to the job, the better it is. As an illustration of this, we may mention the piling of lumber according to thickness, width and length.

On most construction work the lumber is dumped off the cars or wagons and piled indiscriminately all together in one pile. The expense of handling this by having the lumber laid out in separate piles properly labeled with a given thickness, width and length of boards (or a combination of a few different sizes in a pile, where space will not allow separating into each individual one), will be but very little more when unloading than to pile all in one pile. This will make it possible for cheap laborers to get the right kind of lumber which is desired for any particular form and not have to rehandle the whole pile for a particular piece. This plan also makes it possible to substitute cheap labor for all the trucking instead of having it done by high-priced mechanics.

At first thought it may appeal to some that taking away the handling of some of the materials by the higher-priced mechanics and having them concentrate on just one kind is detrimental to the best results. On the contrary, in actual practice the higher-priced mechanics are able to turn out more work by eliminating the heavy, tedious and unskilled part of the work, and they like it better.

The increased output, therefore, is not due to the increased exertion of the workman, but is due to each set of workmen sticking to the class of work for which they are best fitted. This means getting the work out quicker and better.

Standard Methods: Standard methods for doing each class of work must be developed and provision made for seeing to it that the workmen follow out the standard methods. Generally each workman has a method of his own and feels that his method is the best, even though it may be very cumbersome and require a great deal more energy than if done according to a standard method which has been studied and found most economical as to saving of energy and time.

By properly instructing workmen it is possible to have them change their methods according to the standard set and so have the work more uniform and of better quality.

Unit Times and Task Work: Standard methods are determined by a comparison of the length of time and quality of output which result from the same operation being done in different ways. In order to do this the length of time must be determined for each way of doing the work. It is necessary to take the time for each unit operation, so as to determine all the variables which enter into the time. The capabilities of the workman and conditions surrounding the operation have a bearing on the amount of time required to do the work. It takes considerable experience on the part of the one who is taking the studies to be able to determine whether conditions are *O. K.* and the caliber of the men right for the work. There is a possibility of the work being done by an exceptionally capable man, using a very poor method, against a medium man with a very good method. This is where experience comes in to determine this, and also to determine what allowance should be made over and above the net times taken so as to take care of the necessary rests and conditions which come up and which require time.

Where work is properly studied and analyzed and standards set, it is practicable to put it on a task or piece-work basis. This is a fair proposition both from the point of view of the workman and of the employer, as it furnishes a method for paying an exceptionally good wage for a good day's output, and allows a man to earn a much larger wage than could be paid if he did a lot of cheap laborer's work in order to accomplish the results for which he is responsible.

TRENCHING

Trenching is an entirely different type of construction work, and one may naturally assume that it should be handled entirely differently. This is true as to the character of the materials, but the same method of planning and routing has been used successfully and the same general principle of finding the best methods by scientific study. The main difficulty with trenching is that it is very hard to predetermine the kind of material to be encountered. A variation in materials will make a difference in the cost of doing the work and the kind of tools and implements to be used. Nevertheless, a detailed study of the conditions of the earth through which the trench is to go, like taking of borings or digging one section in advance, will give a close idea of what materials are to be encountered and form a basis for planning and routing the work and for really doing it by piece work or task and bonus.

In order to properly plan the trench work it is necessary to give considerably more study to it than is ordinarily considered necessary or profitable. But results show that it pays. A study of the conditions can be used not only to determine in advance the amount of labor, but also whether it will be necessary to provide certain special tools or materials to take care of the conditions, such as dynamite for instance; also whether instead of making a trench of minimum width, it will be more economical to make it wider and not use any sheeting, also the character of sheeting required. The conditions surrounding the job will also indicate at which sections it is advisable to throw all of the excavated materials to one side, or whether it is better to use both sides; also whether it will be advantageous or economical to backfill by hand or use a scraper.

Ordinarily all these things are more or less determined on the spur of the moment by the superintendent or foreman in charge, and considerable delays, involving appreciable extra cost, are encountered through not studying and predetermining these factors.

A study of the conditions also makes it feasible to order materials more economically and have them delivered on the job close to where they are to be used. This saves much of the moving of the material from one place to another which generally occurs on trench work.

The kind of earth encountered, although practically the same in composition, may require an entirely different amount of labor to handle owing to hardness of the gravel, character of clay, etc. A very slight difference in grading of sizes in the gravel will vary the amount of labor considerably; for example, if containing much coarse stuff the pick or shovel will strike a large pebble and make it impossible to go through without taking the second stroke.

Studies taken on this class of work have shown that a better classification can be made by establishing the time and amount of labor it takes to loosen the material by picking and the time and amount of labor it takes to shovel this material.*

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*This is taken up fully in a paper by William O. Lichtner in Engineering Contracting, Vol. XL, Sept. 17, 1913.

A study of trench work has shown that detail studies should be made of the size of shovel, kind of shovel and whether it should have a long or short handle. Also, at what point one kind of implement or another should be used. Study of the various workmen shows that when left to himself each man uses his implements in a different way and for a different length of time. For example, the ratio between the time of using a pick and a shovel for one man is ordinarily entirely different from that of another workman. Yet there is an economical point where a pick should be used and followed by a shovel, and all men should handle it in the same way. The method used also should be studied. It has been found that under certain conditions it is more effective to have the workmen excavate a trench by forming a bench ahead of himself than to have them to go to indefinite depths at one time.

A study of the conditions may also reveal that it is more economical to have one gang of men proceed along the trench doing nothing but picking, while another set do nothing but shoveling. This is used in some cases to advantage where the cut is deep and wide. That such studies as these result in large increase in output is shown by experience.

Carpentry: House carpentry takes up still another phase of construction work, although similar in principle to form construction. We have, however, the same necessity for planning, routing and analysis.

In the first place, it pays to make complete framing plans, not of a fancy style, but with full dimensions and with the lumber designated as indicated in form construction. In certain cases it is possible to order dimension stuff; in others, where houses are being built in groups, not necessarily alike, however, a sawmill near the job is worth while. In any case, the lumber should be carefully scheduled and may be routed as described for forms. This routing comprises the distribution of the material to the mill and to the carpenters who are to work it. Carried farther, the times required to perform the operations are scheduled. Some of the operations handled in this way include framing timbers and joists and studding, erecting, floor laying and finish, the latter including such operations as setting trim; casing doors and windows; fitting and hanging doors of cypress and birch; fitting and hanging window sashes; putting in hardware; setting grounds, base and moldings; fitting blinds, and so on.

CONCLUSION

After all, however, while we might extend these illustrations, the main thing, and that which we wish to leave with you, is not the system of handling materials, routing, etc., but the fundamental principles of the scientific method. First, the determination of standard methods and tools by thorough scientific analysis; and second, means of planning and controlling the operations. The first is the essential—the establishment of standards. We adopt system because this is necessary to see that the material standardized for a certain purpose goes to the right place, to see that the methods, carefully studied, are carried out as planned, to see that the right implements are furnished for the special job.

DISCUSSION

MR. BRODIE: Can these methods be used where there are labor troubles and where the men cannot read English? Is there not a prejudice against scientific methods of management among members of labor unions and other workmen due to the prevailing idea they seem to hold that the chief object is to drive the workmen?

MR. K. H. TALBOT:* I should like to ask concerning the economy in unhitching a team from a wagon during the time of loading and unloading when hauling a distance of from one-half to two and one-half miles; in other words, is it economical to allow the team to rest on the road without supervision, or to allow them to rest at each end under supervision? The fact that in highway construction much hauling must be done over new subgrade and during a period of the year when it is impossible to keep that subgrade in good condition at all times makes automobile trucks impracticable without teams for auxiliary hauling. True it may be economical to improve the road, but any filling of mud holes with stone or extensive improvements in one place would result in a non-uniform subgrade which would materially affect the wearing qualities of the finished road surface.

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Mr. C. D. McArthur:* If I may be permitted, I would like to add two or three notable examples in construction work where scientific methods have been applied. The author spoke of the city of Chicago in street work. In 1914 the city asked for bids on the Wilson avenue tunnel, a 13-foot tunnel seven and one-half miles long to be constructed through Wilson avenue and three miles out under the lake for water intake. The bids when tabulated showed the lowest bid to be $68.20 per foot completed. After careful consideration by the Council it was decided to turn the work over to the Water Works Department and do it by day labor. Civil service and union labor entered into it largely. Five miles of the work has been completed. At the present time that tunnel is costing the city $61.48 a foot.

The large saving up to this time in the construction of this tunnel is due largely, and I might say wholly, to the scientific methods that are being carried on in this work. I have been closely associated with the engineer in charge of this work and I have carefully studied his methods and his analyzation of the work down to the minutest detail. He seems to have studied it in a scientific way; analyzing the possibilities of each workman, the routing of the materials, the number of shafts, the selection of the machinery, the placing of the concrete, the mining, the taking out of the material from the heading to a mixer inside the tunnel, screening it and taking out the finer material, and using it directly without taking it up to the surface and back again.

There is another piece of work, track elevation, being done by one of the railroads entering Chicago. Two or three years ago bids were obtained for this work. A new department (Track Elevation Department) was organized under the chief engineer, which was also asked to bid on the work. The engineer in charge of this department, working directly under the chief engineer, has a keen insight into the scientific ways of construction and is working on those lines. In 1915 he saved that railroad $140 000 in their track elevation work, and in 1916 he will probably save $200 000 over the contractors' estimates.

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There is another piece of work going on in Virginia by railroad engineers who are doing work in competition with contractors' estimates. The work is tunnel lining for a single track about two miles long through which trains are operating, allowing only about 45-minute periods for the placing of concrete. It was necessary to analyze every movement in depositing concrete, and batches of 30 yards are being deposited in 35 minutes regularly every day. I do not think it possible for any one to do the same work unless they go into it in a careful scientific way.

MR. LAYTON: Mr. McArthur's statement is a very fine compliment to the contractors. The city is simply saving the contractor's profit.

MR. C. D. MCARTHUR: I know positively that in the price per foot the city figured in a large percent for loss of time and for the political and union labor interruptions which have been brought about in this work. I know that at almost every Council meeting the engineer has had to go up and explain himself. I have been in his office when 18 and 20 laborers, who have been discharged, came in with their complaints. And I will say that while, of course, the city is saving a contractor's profit to some extent, this work could have been carried on at considerably less price per foot had not so much politics and so many political interruptions taken place.

MR. BRODIE: I think the reason the city did the work so cheaply is because, as a rule, the city does not take the chance of depreciation that a private contractor would.

MR. C. D. MCARTHUR: The entire plant cost of this work is figured in and will be paid for in the work. The Wilson avenue intake tunnel was described by Mr. Henry E. Clausen, engineer of water works construction, in a recent paper before the Western Society of Engineers, Chicago.

Mr. A. Stucki:* First of all, I wish to say that the paper this evening is particularly valuable to all of us, because it gives so many specific examples. I also want to say that I share Mr. Thompson's views regarding the many difficulties we meet in introducing anything of this sort. These difficulties are threefold and originate either with the workman, the foreman or the labor unions, and sometimes all three. Hence it is very advisable not to go too far in the details, so as not to antagonize anyone unnecessarily and so as to leave some things to adjust themselves automatically as the conditions vary.

Take, for instance, the most simple case, that of paper cutting, as mentioned by Mr. Thompson. The insertion of paper strips every so many inches to promote economy may work well with a certain size man, but not with another. A heavy-set man works differently than a slim fellow, one takes a heavier load and moves slower than the other, and on this job both may obtain equally good results if you let them have a chance to adapt their method to their build.

We certainly couldn't have part of the paper subdivided one way and the other part another way to suit the different sizes in the men. This would lead to no end of complications, and we certainly couldn't pick, in filling vacancies, just one size of men, or else we surely would be handicapped in hiring labor. The ame holds true in shoveling earth, in digging coal, etc.

But the more serious aspect is that by going into details that far we cut out all human ambition. This is already done by labor unions in establishing uniform prices, regardless of skill, experience and efficiency of the men, and if we do it in this other way, the workman surely will be nothing but a tool, decidedly degrading for any human being. He does not care to be told just how often he should stoop per minute, as long as he gets results. We will not get his goodwill either, and that we must have to get results, and anyone who tries to run an establishment without it will get left.

The foreman is the other factor in making such a system a success. But we must not forget that he is a busy man, that he possibly has spent a great many years in the same shop, that he knows his business well and that he has had splendid results for

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many years, both as to quality of work and output. Therefore, he certainly is entitled to a great deal of consideration in planning to improve the efficiency, and here again we should be doubly careful not to go beyond a practical limit.

The third consideration in the introduction of a scientific system is the labor union, and I am glad that Mr. Brodie has already brought out this question. Here again it is very desirable to stay within certain limits, so that no objection from this side can possibly be raised.

After all, Mr. Thompson struck the keynote when he said that the man should be paid in accordance with his individual accomplishments, and this is the true principle on which any practicable system must be built. This means that we must have individual control, i. e., that the work must be parceled off to each man or each "gang," so that the work after it is done can be traced back to the man who did it.

When we first started to build steel cars each gang of riveters took car by car, which had no number assigned until painted and stenciled. Then the railroad inspectors, before the cars were accepted, went over the whole car and always found many loose rivets, but having no means of identifying the cars with the riveters we had to designate a gang of men to follow the inspectors and cut out and replace the rejected rivets. After a while, however, each car was given a shop number and each detail and subconstruction going into it was given the same number long before the erection of the car proper began. This way the record showed who did the work and the problem of inspection was made easy, since each gang was now compelled to cut out and replace their own bad rivets, and to do so without pay.

Mr. William Archie Weldin:* I was particularly struck with one sentence in Mr. Thompson's paper: "To obtain results such as these requires time, patience and a thorough appreciation of the ultimate good that will be attained." The work of the masters of scientific management has been appreciated by laymen, as well as engineers, all over the country, and the managers of large enterprises everywhere are turning to their engineers for

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advice as to how they can use scientific methods. Engineers should be prepared with such advice, either as to how the methods themselves can be introduced or whether to employ certain experts for that purpose.

As a general rule, while managers realize that very profitable results have been obtained by the use of scientific methods, few appreciate how much preliminary study and time is required before such results can be realized.

I think it would be very valuable and interesting to the engineers present if Mr. Thompson would give us some idea of how much preliminary work would be required in the case of a large construction organization doing large jobs in different places which desired to introduce the best methods. How much time would be required before the saving in cost of construction would equal the extra expenditure expert advice, time study, etc. Of course, I realize that this question cannot be answered categorically, but would it be in a typical case a matter of weeks or of years?

Some time ago I was asked to advise as to how far the methods of scientific management would be immediately available for use in bituminous mines with particular reference to underground work. As far as I know, nothing has been done in this line at that time, and I went to Philadelphia and consulted with Mr. Taylor and Mr. Hathaway. As I remember the conversation, Mr. Hathaway said without knowing anything about the particular difficulties of underground work and conditions, but judging from experience in attacking new industries, it would require probably three years of study and labor and expert attention before the reduction in the cost of mining would equal the expenditure. I suppose that was an extreme case. On account of the amount of work that has already been done in the case of construction, a great deal of data would, perhaps, be immediately available and a great many methods could be put in at once, and I should judge that the preliminary period would be very much less than in the case of mining.

Another point along the same line is the state of the art of the application of scientific methods to construction, such that it would be feasible to accomplish really valuable results by simply taking the present employes of an existing organization and training them in the new methods, or is it generally advisable to employ an expert whose particular business it is to go from organization to organization introducing these methods and temporarily controlling the work?

Would it be necessary to make complete time studies to establish standard methods and standard times, or can certain standards be adopted at once direct from the work that has already been done, in the case of making forms, mixing and depositing concrete, etc.?

MR. BRODIE: I would like to know how the efficiency men can jump from something like paper making to building construction and figure down the details of the business to make a saving. They must be geniuses to jump from one business to another like that. Take the paper line, there might be ten breaks an hour and the efficiency man would not know what the trouble was. It would take quite a while for an efficiency man to get on to that game.

MR. SANFORD E. THOMPSON:* Mr. Brodie has referred to labor problems and to the employment of men who cannot read English. The method of giving out work depends on the character of the workmen and the type of work. For instance, you would not give out a form with a lot of matter written on it to one who could not read. You would simply give out a check, or register it from the office.

With regard to the attitude of labor, this work is being carried on at the present time with the present conditions of labor, and is being handled with union as well as non-union men. Under certain conditions, however, especially among the building trades, care must be exercised in taking hold of the work.

There is prejudice on the part of certain unions, and it is based on the erroneous apprehension that the object of scientific methods is to speed up and drive the men. There has been more or less reference in the papers to the work at the Watertown Arsenal. They have been introducing scientific methods there with excellent results, both as to reduction in cost and increase in pay to the workmen, and the workmen in the shop like it. The unions, however, working from the outside have opposed it and brought out many unfair and untrue statements, and the bills before Congress I mentioned have been put in from these sources. Eventually, I believe, the labor unions will come around to it because, when the work is handled in the right way, it is by no means a speeding up. In carpenter work, for example, the largest part of the gain is made by the proper placing of the material, arranging to use the right lumber, and showing the workman just how to do his work in the quickest way. He is relieved for one thing of carrying the lumber and doing what is really laborers' work. In a good many union shops scientific methods have been introduced.

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*Author's closure.

In reply to Mr. Talbot's inquiry with reference to the resting of teams, I may say that it is governed largely by the number of miles traveled per day. This distance is influenced in turn by the condition of the road. On ordinary construction roads a total travel of 17 miles is a fair day's work for a horse, and whether the time during loading gives him the proper amount of rest depends on the length of haul, the number of hours in the day, and the number of men loading. On short hauls the time of loading gives too much rest and on long hauls too little rest. This matter is discussed quite fully in Taylor & Thompson's "Concrete Costs," pp. 232 to 240.

Mr. McArthur's illustration of the results produced on large work by definite planning is very interesting. Even if the item of profit and certain other features are not considered, in view of the handicap under which city work is placed in connection with the payment of its labor and the selection of its labor and the politics that enter into it, it seems to me a wonderful showing if they can do the work for the same price as the lowest bidder.

Mr. Stucki has mentioned several difficulties in the handling of work by the methods we have indicated, especially bringing out the difference in ability of different men and his fear of cutting out ambition. As a matter of fact, it does not work out in that way at all. Take, for example, the question of the lift a man should take. If you give the right man the right job you have the proper kind of work for him to do and the proper load and lift that is best for him. You may have to change the men around to quite an extent to get the heavy man on the heavy work and the lighter man on the work for which he is fitted. If the labor market does not permit this, it is frequently a good plan to divide the men or women on a certain job into two or three grades, giving different instructions to each, and the higher reward to the grade capable of the greater amount of work.

As to taking away a man's ambition, this is a point that is brought up quite frequently, and the only trouble with the criticism is that it does not jibe with practice; it is contrary to fact. As an illustration, take the paper-cutting operation referred to. Mr. Lichtner made, about three years ago, some studies on a man cutting paper. The man had been used to the ordinary way of taking the amount of lift that he chose and handling the paper just as he wanted to. He was naturally a little bit cranky. He was going his own gait, and since this job was the first one studied in the plant he did not know what the effect with task and bonus would be. About two years later some other cutting machines in that same plant were to be standardized, and Mr. Lichtner took some more studies on this same man who had been at work on task and bonus during this period. He tumbled all over himself to point out suggestions that would help along and improve the work, and to do what he could to help the thing along. As a matter of fact, the plan does not work in the way of taking away a man's ambition or incentive. A man likes to do a good job. If he can be shown how to do the job in the best way he will take more interest in doing it that way than doing it hit or miss. I have quite a number of letters from workmen speaking of how much more interest they take in the work because of this incentive and the training to do things well. I was in a clothing shop where the type of people was much above that of the ordinary clothing operatives, just because of this training and personal attention that was given them. It is really an education. It educates them to do one thing well, and it makes them better not simply in connection with this one operation, but in all others, just like training in college. You go to college not because you expect to put into effect all of the things you studied in college, but because the college shows you, if it is any good at all, how to be able to study out a new proposition and bring it to a conclusion.

The foreman, as Mr. Stucki indicates, must thoroughly cooperate to make the plan a success. There is no question that where the foreman is an old experienced man he is a pretty hard man to budge. That a young man can go out, make analyses, and produce better goods and increase the output, is a hard thing to convince a man of this type. I feel that a foreman who is over forty or forty-five and has always worked by rule-of-thumb methods is almost hopeless; on the other hand, we find the younger men ready to take hold and appreciate the advantages of scientific methods in reducing their labor and increasing output.

With reference to the time required to accomplish results mentioned by Mr. Weldin, it is probable that the answer made by Mr. Taylor and Mr. Hathaway would still hold true with reference to mining operations. It might take three years before you would get any definite results, because it would be overcoming methods that have been in use for years and years, and probably the introduction of the machinery as well as changing the organization. In some classes of works results can be obtained immediately. The president of a construction company, which we started along these lines a few years ago, told me that on the first job under scientific methods he saved $10 000. This, however, was unusual. On form construction work one can get results on the first job if your foremen and superintendents support it. If they buck, it will probably not get anywhere. Other classes of work range in between this and the mining referred to.

The development of scientific methods should be accomplished chiefly within the organization. At the same time outside help, in large measure of an advisory nature, is really essential to show your own men how to attack the problem and to provide fundamental data. Do not try to go too fast, but develop the methods slowly, separating the planning from the executive work and gradually training the men in your own organization. The advantage in getting outside advice is to benefit by the methods that have been tried and proved out in other places and be able to adapt them to the particular type of work under consideration.

Mr. Weldin has asked whether standards are available for use. As a general proposition you have to make some new studies, but frequently can utilize records to a considerable extent. In Taylor & Thompson's "Concrete Costs" there are valuable tables of times and costs. A good many of them are based on ordinary contract work instead of being based on piece work or task and bonus, yet they can be used relatively to a considerable extent even for this. Values are also given there for form construction and unit times. But even with all this you have got to take more or less time studies on the job to tie the values. But the main thing is to develop your organization to be able to handle and maintain the control after you get the studies.

In reply to Mr. Brodie's references to different types of work, the idea in management is to make specific studies of certain things, taking them up one by one, and going into each more in detail than the people on the job have done or can do. After a man has become experienced in stop-watch work and can make detail studies, watching the way the workmen handle the work, he can make suggestions and show how a thing can be done better than the foreman who has been on the job all his life and has handled it in a more or less superficial way. It is the scientific principle of digging into a thing and getting the results by analysis. When you come to routing and distribution of the work you can use the same general methods in the different classes of work.

If the efficiency man, as you call him, is going to revolutionize things by looking at them, he certainly is a marvel. But the man who is going to tackle a paper mill, instead of watching the breaks will go back to the source of the trouble and tackle the beating engines, the rag stock, and the pulp, and the material that goes into the paper. He will study the methods to be employed in determining the amount of water in the rags and pulp, and where he finds the practice is to run the beating engine anywhere between one and a half and four hours to produce the same quality of paper, he standardizes this by definite specific studies; and he will get the correct processes more quickly than a man who knows all about paper making and does not tackle it in the scientific manner.

In closing, I wish to call attention again to the fact that the essential element in what is termed "scientific management" is not the system of operation; it is the philosophy which involves the scientific analysis, the fixing of definite standards for materials, implements and methods, the selection and training of the workman, and the intimate friendly co-operation between the management and the men.

WHAT CAN BEST BE DONE TO ADVANCE THE INTERESTS OF THE ENGINEERING PROFESSION IN THE UNITED STATES?

By J. A. L. WADDELL*

That there is always something to be done to advance the interests of the engineering profession goes without saying; for if the existing status of affairs were such as to make this statement incorrect, it would indicate that no improvements are being made in engineering and that none are needed—which condition is inconceivable. The question is "how serious and pressing are the conditions calling for concerted effort to improve them on the part of American engineers"; and that matter should be investigated thoroughly before attempting to indicate the possible remedies.

Early in 1915 Dr. George F. Swain, the eminent engineering professor of Harvard University, and Past President of the American Society of Civil Engineers, delivered an address before the American Institute of Electrical Engineers, in which he stated that, on the whole, engineers are deficient in clarity of thinking as compared with lawyers, and in both clarity of thinking and breadth of view as compared with lawyers and business men. He gave it as his opinion that the engineering profession is not appreciated at its full value, and that the engineer does not receive the recognition in public life and as a leader to which he is entitled by his attainments. Dr. Swain stated also that while the compensation of engineers has increased of late, the fees which they receive are not as large as those paid to lawyers and doctors, the reason being that the engineer does not appeal to sentiment while the lawyer and the doctor do.

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Dr. Swain also remarked that the best men of the community take up law, and that "legal training and experience, on the whole, train men better to think straight and reason logically than the engineering training."

Speaking of breadth of view, he says: "Here, again, there may be doubt, but I similarly question whether today, and in the past, the training of the engineer has given as much grasp of subjects and breadth of view as has the training of the lawyer and the business man. I fear that the engineer concerns himself in college, and after college, too much with the minor technical details of his profession, and does not accustom himself to study, does not take interest enough in the broad questions affecting the community in general."

Finally, Dr. Swain claims that "the fact that engineering is to so large an extent a mathematical subject is one of the main reasons why the engineer is not recognized"; also that "there is scarcely anything that tends more to narrowness of view than dealing all the time with problems which can be solved only by rigid mathematical processes, because the great questions that confront us are not mathematical; the data are shifting, variable, and the human element comes in. Therefore the man who is accustomed to solve his problems by mathematics, and who can only do the solving in that way, finds himself at a loss in the practical affairs of life—mathematics do not apply."

These various statements of Dr. Swain's are emphatically drastic; and probably they had to be made so, if they were to effect any good purpose. The immediate result of his address was the obtaining by the *Engineering Record* of a concensus of opinion on the points raised from a dozen or more engineers and professors of engineering standing high in the profession. These, while in the main agreeing with the general statements of Dr. Swain, differed with him on many points of detail, and a few of them were almost entirely opposed to his views.

Although the speaker was not invited to participate in the discussion of Dr. Swain's paper, he takes the liberty of stating that, like the majority of those who took part in it, he endorses many of the claims made; but he is not prepared to concede that the leaders in engineering are in any way inferior to the leaders in the other learned professions in clarity of thought, straight thinking, or breadth of view. It may be otherwise, however, with the rank and file of engineers, because their training, experience, and general manner of life are far from broadening.

Certainly Dr. Swain has given good evidence, which has been fairly well endorsed by his critics, to the effect that there exist rather "serious and pressing conditions calling for concerted effort to improve them on the part of American engineers."

If other evidence concerning the inferior status of the engineer be necessary, the following quotation from an editorial in the *Engineering Record* of November 20, 1915, upon the subject of the Philadelphia Valuation Conference, will afford some that is very much to the point:

"KEEPING THE ENGINEER IN HIS PLACE.

"As is usual in these mixed gatherings, the engineer was kicked around considerably by the lawyer and the economist. According to Professor Gray, the engineer is in no way fitted to discuss questions of value and wealth, and his testimony on these matters is never regarded seriously by the economist. In general, neither the economist nor the lawyer hesitates in these discussions to put the engineer in *his* place, but both are shocked when the engineer attempts to define *their* functions. Under these circumstances, is the engineer going to stay 'put,' or is he going to assert himself? Is he going to admit that the *hours* he spends on the valuation details of a plant with which he is familiar are worth less than the *minutes* spent by lawyers and economists on details of plant with which they have no acquaintance?"

Again, in the *Engineering Record* of June 5, 1915, there is an editorial which quotes from the report of Mr. C. E. Drayer, Chairman of the Publicity Committee of the Cleveland Engineering Society, made to the Chicago Association of Commerce. Among other forceful remarks he makes the following statement: "When two vacancies occurred in the Interstate Commerce Commission a year or so ago, the suggestion was made to one who had the ear of the appointive power that it would be desirable to have one of the vacancies filled by an engineer. He replied that such a position required a judicial quality of mind, and that the incumbent could surround himself with all the expert service needed. His answer implied that an engineer could not be found possessing the necessary judicial quality of mind. It should be stated that the man who gave this reply was a lawyer."

Once more—in one of the richest and most active counties of the Middle West a vacancy due to the death of the incumbent occurred lately in the office of county engineer; and the politicians succeeded in having the Governor of the State appoint a lawyer to the position for the unexpired portion of the term of office. Of course, he relied upon the assistant engineers to attend to all the technical work; but it is claimed that he has since stated that there is not an engineer in the entire county capable of filling the position because of its political characteristics.

Do not the preceding facts constitute sufficient evidence that there is a necessity for American engineers to make a concerted effort to advance the interests of their profession and to change materially those existing conditions which cause the unsatisfactory state of affairs? There can be no doubt whatsoever about the expedience of such concerted action; hence it will be well to summarize the undesirable conditions and the alleged deficiencies in the general make-up of American engineers. Those most commonly recognized or claimed are the following:

A. The importance of the engineering profession is not at all adequately recognized by the general public.

B. Engineers as a class are not paid enough for their services.

C. Engineers are not sufficiently often appointed to high executive positions for which their special training and knowledge eminently fit them.

D. In most joint work where a lawyer and an engineer are employed, the lawyer is usually given the leading part and the greater compensation, and the engineer is forced to fill a subordinate position with small pay.

E. Engineers do not take a proper interest in politics; and hence are not given any of the political plums, these going generally to the lawyers and the business men.

F. Engineers are too modest for their own good, hence their great works are comparatively unknown outside of the technical world—and often none too well within it.

G. Engineers as a class are lacking in the ability to speak readily and convincingly in public, and hence cannot influence the masses or guide their efforts towards the accomplishment of important *desiderata.*

H. Engineers are trained too closely along narrow mathematical and technical lines and not in those which develop them broadly as men and as citizens.

I. Engineers, as a class, do not pay sufficient attention to the proprieties, do not dress with sufficient care, do not have sufficient dignity, and rather look down upon a man who concerns himself seriously with such matters of minor importance as personal appearance and the general requirements and trifling obligations of society.

J. American engineers, as a rule, have not a thorough command of their native language in either writing or speaking, owing mainly to the fact that they have been taught to look upon language-study as of far less importance than mathematics or technics.

K. American engineers, because of their narrow training, are not interesting members of society, in that they are unable to converse well upon general subjects, and because they are not keen in regard to any matter that lies without the pale of their professional life.

L. There is a lack of ambition and earnestness among the rank and file of the engineering profession, making them content with earning their comparatively small monthly wage and with living a hum-drum life, and preventing them from advancing beyond mediocrity.

M. There is as yet no adequate general code of ethics established for engineers; and for that reason the profession cannot stand as high in public estimation as the other professions which have such established codes.

N. There is a lack of harmony among engineers as a body (due possibly to the need of a proper code of ethics, but probably also to a number of other important reasons), which tends to hold back the progress of the profession.

O. The field of activity of the American engineer is too restricted—both from a business standpoint and geographically.

As before stated, these are the common allegations made against engineers and their vocation by both its members and the laity; but please understand clearly that they are not those of the speaker, for while he cannot deny the existence of numerous shortcomings in the engineering profession, he maintains resolutely that it is the grandest and most worthy profession of them all, in that to it are due the wonderful progress of mankind which has characterized modern times, and all the comforts and conveniences of life that make it truly worth living instead of the heavy burden which it was often claimed to be by our ancestors of a few generations ago.

The speaker does not like to confess that the lawyer is a clearer or more direct thinker than the engineer. What is the test of clear thinking? What is the measure of the value of such thought? In the engineer's case, clarity of thought is evidenced by his works successfully resisting or controlling natural forces through the adaptation of existing physical conditions to the service of mankind. The value of this service to society is proportional to the increase in the sum total of human satisfaction which it accomplishes.

In the lawyer's case, clarity of thought is best attested by the winning of a lawsuit—and in this connection it must not be forgotten that for every winning side there is also a losing side, and that, therefore, there must often have been *a lack* of clear thinking to the same extent as there was *an existence* of clear thinking. Also in the lawyer's case; the winning of a suit hinges upon a jury's verdict or a judge's decision, and not upon immutable laws of an orderly universe. The value of the lawyer's service also to society is to be measured by the increment to the sum total of human satisfaction which his efforts produce. There is satisfaction of some degree for the client whose case is won, but, on the other hand, there is equal dissatisfaction for the client whose case is lost. Hence by adding these two results it is seen that there has been no gain but simply a maintaining of the *status quo.*

It may be urged by some of the champions of the legal profession that the lawyer's service to society is rendered when he acts as a legislator or as a judge or other public official, and that his constructive work in framing new laws or in making decisions of record is of great benefit; but it must not be forgotten that this constructive work is later subjected to the destructive efforts of other lawyers in their endeavors to win cases for clients. Hence, considering the legal profession as a whole and the entire machinery of the courts, the principal service rendered to society by lawyers is, as before indicated, preserving the *status quo.*

Notwithstanding, however, anything that may previously have been intimated to the contrary, in respect to the various enumerated allegations against our profession, the speaker must confess that they all contain in them more or less of truth; and that is the reason why they have been stated by him so plainly.

Enough, though, has now been said about the existing difficulties, defects, and general undesirabilities connected with our profession; hence what follows will deal essentially with the remedies therefor and with the manner in which the interests of American engineering may best be advanced. This subject involves two underlying questions:

First: What *are* the interests of the profession? and,

Second: What is the *limit* of their advancement?

Fundamentally, the interests of the profession are inseparably linked with those larger interests of the public which are paramount for the progress of mankind; consequently, it may be stated, without fear of contradiction, that the status of engineering can be improved mainly in one way, viz., by increasing its usefulness to humanity. This object is the true *raison d'etre* of the profession, hence the augmenting of its effectiveness will certainly react favorably upon the aggrandizement of its appreciation by the general public.

The amassing and the consumption of wealth by the people constitute the most important factor in the process of attaining the maximum of material satisfaction for both the individual and the community, which satisfaction is the true measure of national progress; and this can be secured only by a continuous and progressive development of the country's resources. With such development the engineer is directly concerned, and he is responsible in a large measure for that development. This, in a broad sense, is the service that he renders to mankind. A keener appreciation by the general public of the engineer's real function in society is greatly to be desired; and its accomplishment constitutes the first effective step to be taken in advancing materially the interests of the profession. This is the psychological phase of the problem. A proper recognition is essential so that adequate compensation may follow.

In order that the engineer's efficiency may increase and that he may be able to respond to the growing needs of a highly complicated society, it is necessary that there be a continual growth in professional knowledge to enable him to meet such demands. Again, to render it more certain that a proper compensation will be the reward of the engineering profession. it is desirable that the supply of engineers be fairly well adjusted to the average rate of development of the country so that no large surplus will be forced into competitive methods for obtaining business. A proper balance should be maintained between the number of engineers of all lines and the total amount of capital available from time to time for investment.

We thus see that the engineering profession is especially interested in securing:

1. Proper recognition.
2. Adequate compensation.
3. Increase of professional knowledge.

4. Proper balance or adjustment of various classes and numbers of engineers to meet the needs of a developing country.

This country, measured by its density of population, or by the wealth per square mile, or by the wealth per capita, is far from having attained its maximum development, as the following comparison of it with England will show:

	United States	England
Density of population,	26	376
Wealth per square mile,	$35,900	$661,000
Wealth per capita,	$1,390	$1,760

From this comparison can be conjectured something of the development that yet awaits the United States. There is nothing improbable in the assumption that this country will attain and even surpass eventually the condition above tabulated for England. In so doing, its resources must be more highly, efficiently, and economically developed than they are now; all of which means an increasing demand on the engineering profession for generations to come. Here is the need for broad vision and clear thinking. Here is the need for a continuous adjustment and readjustment of the profession to the requirements of a growing society. It is not sufficient simply to maintain a *status quo*, but it is necessary that progress be anticipated; and in such anticipation the engineering profession should be leaders—not followers.

Permanently to advance the interests of humanity means to enlarge those interests in every way possible that is consistent with an increase in the sum total of satisfaction to society.

To secure greater recognition requires that a more extended publicity be given to the works of engineers and to the results and effects thereof upon the community in which those works exist. It is not sufficient merely to describe the technical details of a structure or other piece of construction work; but it should be shown how such a structure or construction affects the community by drawing a sharp contrast between the conditions preceding the improvements and those subsequent thereto. It is this that the public can best understand and appreciate.

Again, greater recognition would result to the engineering profession, were more of its members appointed on boards, commissions, committees, etc. This can be brought about mainly by the individual engineer making a practice of taking part in the affairs of the community in which he dwells. Further recognition could be secured through the various engineering organizations by making, from time to time, recommendations to legislative bodies for constructive legislation. As before indicated, greater recognition of the engineering profession and a keener appreciation of the service it renders to society must come before very much improvement can be expected in the way of remuneration. Furthermore, conditions which lead to undue competition between members of the profession are to be corrected by adjusting and readjusting occasionally the supply of engineers to meet the demands of a developing country.

To bring about any great increase in technical knowledge calls for organized and cooperative effort on the part of the members of the profession. A survey of existing technical knowledge should disclose wherein are the gaps needing to be filled. The practicing engineer can well draw on his own experience in locating such deficiencies. The filling of those gaps and the further extension of existing knowledge can best be undertaken by the numerous engineering schools working under a general program laid down by a joint committee composed of members of the various engineering societies.

The preceding remarks concerning what can be done to advance the interests of the profession are of a rather general nature, and henceforward it will be necessary to enter more specifically into detail.

The life of an engineer may be divided into three epochs: first, from boyhood up to the time of graduation from the technical school; second, as a young engineer in practice while earning his spurs in the profession—say, on the average, for fifteen years; and, third, thereafter as an expert in his line of specialization. As the only truly effective way to improve the status of the engineering profession is to augment the efficiency and increase the capacity of the members of which it is composed, it will be pertinent to discuss what should be done both for and by the members during each of the three said epochs.

FIRST EPOCH

The student portion of an engineer's career is by far the best time of his life to produce upon him lasting impressions that will benefit him later professionally and thus tend to aid the profession itself by increasing his efficiency. Unfortunately, it is difficult to get hold of and do anything for the embryo engineer before he enters the technical school, because boys often do not make choice of their calling until they are about ready for college life, and some of them not even then. Of course, if the education of boys in general were materially improved by any means, the benefit of such improvement would eventually be felt by the engineering profession as a whole; but this is not the time nor the place to discuss at any length elementary education, suffice it to say that the most prominent deficiencies in our grade schools and high schools are failure to teach the students how to think and to concentrate the mind, ineffective instruction in the English language, neglect to install thoroughness into the students, permitting of faulty and loose speech, ignoring the necessity of accuracy in mathematical work and in composition, teaching dead languages which are of no earthly use and failing to teach properly modern ones that would be of real value, the nonrecognition of individuality in the pupils, and the encouragement of mediocrity at the expense of superiority by endeavoring to bring all the students to a common level of scholarship.

The correction of these and other faults in the American system of early education is a national matter of great importance, and not one to be undertaken by any single profession, unless it be that of pedagogy.

The improvements necessary for engineering courses in general in order to increase the efficiency of the students as much as practicable, arranged in the order of their importance, in the speaker's opinion, are as follows:

1. Extending the duration of the course from four to at least five, and, preferably, six years; or else the establishment of separate schools for post-graduate engineering work of all kinds.

2. Arousing the enthusiasm of the entering freshmen in respect to the profession of engineer, showing them its grandeur and its usefulness to mankind.

3. Inculcation of a love of study and work for their own sake and not mainly because of the money that can be earned thereby.

4. Instruction as to how best to study so as to save time and labor, or, in other words, the economics of mental effort.

5. A thorough, elaborate, and systematic study of sound business-English, extended over each year of the entire duration of the course.

6. A general broadening of the course of study so as to include thorough instruction in such important lines as economics, history, oratory, and business.

7. Making the study of the Spanish language obligatory and that of any other foreign modern language optional.

8. Improving fundamentally the study of all foreign languages, so that upon graduation all the students thereof shall be able to read, write, and speak them fluently, correctly, and gracefully.

9. Study of the art of systemization and its application to all lines of activity.

10. Teaching of ethics for engineers.

11. Accumulation of individual libraries, and showing how to utilize them properly.

12. Establishment of better opportunities for acquiring individual scholastic distinction by the students.

And now a few words of dissertation and comment concerning these twelve *desiderata.*

DURATION OF COURSE

For thirty years the speaker has been preaching the necessity of five-year courses in civil engineering. As long ago as that there was a real need for more time in order to learn the fundamentals of the general science or art of engineering as then known and understood; but since then the amount of knowledge concerning all the numerous branches thereof has increased many fold, and, consequently, the truly necessary things that an engineering student must learn today in order to obtain a proper technical training cannot be taught him in a four-year course, even if there be eleven working months in the year—as there should be when field work is properly covered.

In order that technical education may keep pace with engineering progress, one of two things must be done—either the engineering curricula in the universities and technical schools must be lengthened, or else they must be modified so as to cut out some of the more advanced courses, in order to permit of more thorough instruction in the remaining ones and of the addition of many culture studies, leaving those students who desire more complete technical education to obtain it in post-graduate engineering schools. In any case, we certainly need more post-graduate technical courses than are now available for the youth of the United States.

On the other hand, the number of trade schools should be increased so as to provide practical education for artisans, draftsmen, and the lower-grade engineers who have not the desire nor the means to take a full technical course. Such men are necessary for the proper development of this country and for the advancement of engineering therein; because it has to be recognized that all engineering students cannot become famous engineers, and that there must be "hewers of wood and drawers of water" in our profession as there are in all other walks of life. The routine work must be done by routine men who are not too ambitious, nevertheless such men should be thoroughly trained for the work they will have to do.

It is probable that we could dispense to advantage with a number of the general engineering courses that we have in the United States, dropping out the weak ones and enlarging and improving the others. Those thus dropped might well be converted into trade schools.

In the speaker's opinion, the various changes he has just suggested would tend towards the improvement of engineering education in general, for we should then turn out annually a few highly educated technical graduates, a better average grade of other engineers, and competent artizans, draftsmen and surveyors.

ENTHUSIASM

On a number of occasions the speaker has publicly expressed his conviction that the general average of efficiency of the entire student body in any technical school can be raised fully twenty-five percent by arousing the enthusiasm of the entering freshmen for the profession of engineering by explaining to them at the outset of their student life what a grand thing that profession is, how it is the fundamental cause of the world's progress in all lines, and how hard one has to struggle in order to do his share of effective work in the development of mankind and of general welfare. To this end a few years ago there was compiled by the speaker and his partner a book of "Addresses to Engineering Students"; and an endeavor was made by them to have the work sold to the entering freshmen at a price a little below actual cost, and to ensure its being read by them through quizzes thereon by the faculty. A certain amount of success has attended this endeavor; but the professors of engineering, as a rule, have not aided the editors of the book to the extent that was originally hoped. There is still a small but steady demand for the work: and it is being used in a few technical schools as a text book in the English department.

It is not enough, however, to enthuse the entering freshmen; for their interest in the profession should be stimulated from time to time throughout their entire course by lectures on the subject from both the faculty and practicing engineers.

The remark has been made that showing to the entering freshmen what a vast amount of work lies ahead of them before they can attain success in engineering will result in discouraging some of them to such an extent that they will give up at the very outset the intention of studying to become engineers, and thus the technical courses will be depleted of students. If such a statement is true, what a fine thing that would be for our profession! Because it would be the weaklings and those lacking in courage who would drop out and the mentally strong and courageous men who would continue. Thus the average of efficiency would be augmented and the profession would be served by better men. This last is an important *desideratum*, and everything possible should be done by engineers in general to induce the brightest youths of the country to enter engineering in preference to other callings. Such a result can be attained by lectures to high-school students, articles in the daily press and in high school papers demonstrating the advantages of engineering as compared with the other professions, and seizing every opportunity to talk to young men and boys, both individually and collectively, so as to extol the calling of the engineer.

LOVE OF STUDY

The inculcation in students of a love for study and work is no easy task. It can best be done by their instructors in both the preparatory schools and the technical institutions. To attain this end the instructor must first secure the respect and affection of his pupils. He should endeavor to instill into their minds the fact that the great attainments in life are not to be measured by dollars and cents but by their usefulness to the human race. Lectures on this subject by men of prominence will often produce a lasting impression upon young men and boys who are of an earnest nature.

HOW TO STUDY

It is very seldom that boys and youths are taught how best to study and work, how to economize their time and labor, or how to attain the maximum of effect with the minimum of effort—in fact, too little is known about these important matters by the instructors themselves. They should be studied thoroughly by both teachers and pupils; and the results of such studies should be put into practical application. Every teacher who is worthy to be included in the noble profession of pedagogy should devote to this matter his deepest attention, for upon his practical solution of the problem will depend the success of his life's work.

ENGLISH

Too much cannot be said about the ultra-importance to all American engineering students of a thorough command of their native language. Without it their success as engineers is almost sure to be mediocre—or worse. In every year of the entire curriculum there should be courses in the study of English; and in the technical courses themselves the professors should insist upon the employment of good English by all the students in reading, writing, and speaking. The language instruction given in technical schools should be of a thoroughly practical nature—prose instead of poetry, forceful diction instead of excessive elegance of expression, business language instead of flowery oratory. The glaring neglect of the English language in many of the technical schools of the United States is a disgrace to the country; and, until it is overcome, engineers as a class will have to content themselves with occupying a position of social inferiority, as compared to the members of the so-called learned professions. A thorough command of his native tongue is the great and effective lever for any engineer to use when prying his way to success and recognition.

CULTURE COURSES

Technical teachers are beginning to awaken to an appreciation of the fact that it has become absolutely essential to instruct their students in other lines than mathematics and technics in order properly to fit them for their life's work, and that American engineering courses will have to be broadened so as to provide thorough instruction in economics, history, oratory, logic, business, and other studies of a non-technical nature. Without a good grounding in such lines the engineer of the future will continue to be a narrow technist—unappreciated by the community, and insufficiently compensated for his labor.

SPANISH

For many years the speaker has advocated the obligatory study of the Spanish language in all the technical courses of instruction given in the United States; and since the advent of the present war he has been harping on the subject continually. Our country is destined ultimately to dominate the trade of the Latin-American countries; and the present is the opportune time for the speedy accomplishment of this object. Those countries all have to secure capital from outside in order to develop; and for ten years there will be none available from Europe, as the nations there for some time will be borrowers —not lenders—of money.

There are certain things, though, which Americans will have to do before they can succeed in securing the Latin-American trade—and one of the most important of them is to send to the Spanish-speaking countries agents who have a thorough command of the Spanish language. To that end Spanish should be taught at once in all the grade schools, high schools, technical schools, colleges, and universities of the United States. Not only should it be made the one obligatory foreign language-study, but it should be taught scientifically and thoroughly by instructors whose native tongue is Spanish. Any attempt to teach the language by English-speaking instructors will result in failure. The speaker has seen in his home city how effectively Spanish can be taught in a few months to earnest young men and women in night classes; hence he does not hesitate to affirm positively that it is perfectly feasible to teach Spanish to the youth of the United States so thoroughly that in a year or two they will be able to read, write, and speak it creditably, fluently, and effectively, and so that they will be able to do business by using that language solely as a medium.

If this country is to dominate the Latin-American trade, there certainly will be a great call for American engineers t-go to the Latin-American countries to take charge of important constructions, to survey and build railroads, to report on business projects involving engineering work, and to advise capitalists about investments of various kinds. In fact, it is essentially through its engineers that the United States will succeed in securing the Latin-American business; hence it is imperative that American technical men shall have a complete mastery of the Spanish language. Moreover, no engineering student need complain that he is wasting the time that he puts on the study of Spanish on the plea that he has no intention of ever going to either Central or South America; for the reason that, in order to obtain a thorough knowledge of one's native tongue, it is necessary to struggle with the intricacies involved by the grammar of at least one foreign language. No man can be said to have received a polished education until he has been drilled by the study of a foreign tongue. It was the recognition of this principle that for centuries caused the enormous waste of labor involved by the practically useless study of Latin and Greek. No statement can well be made too strong concerning the necessity for young Americans, and especially those who either are or intend to be engineers, to study thoroughly the Spanish language.

OTHER FOREIGN LANGUAGES

It is important also to teach much more thoroughly than is customary in the United States other foreign languages than Spanish—for instance French and German. In regard to this, one should remember the old proverb that "anything which is worth doing at all is worth doing well." A knowledge of French is a gentlemanly accomplishment for any man, and a knowledge of German is useful in certain lines of scientific research; but a smattering of either language is of no value whatsoever to any one, excepting only for the mental training that its study gives. That training, of course, is the more effective in proportion to the thoroughness devoted to the study of the said foreign language.

STUDY OF SYSTEMIZATION

Systemization in all that one does is one of the most important habits that anyone can acquire; hence its principles should be constantly inculcated into technical students by the faculty throughout the entire curriculum. Systematic habits of study, thought, and work are a necessity for the greatest success in any calling, and this ***desideratum*** cannot well be over-rated.

ETHICS

It is essential for engineers to learn their system of ethics at the technical school so that as soon as they start out in professional life they will be able to put it into practice and thus avoid making grave mistakes which might mar seriously their future careers. Without a sound ethical system thoroughly established and practiced, the engineering profession cannot possibly attain its acme of influence in society; because it is only by concerted effort that such attainment is possible, and concerted effort is impracticable without a system of ethics, universally recognized and followed.

INDIVIDUAL LIBRARIES

Much of an engineer's success depends upon the size and character of the technical library which he accumulates No one can do great work in any profession without having at hand a reference library. This fact should be driven into the minds of all technical students at the beginning of the course of instruction, and they should be reminded of it from time to time by the members of the faculty. It should be considered a deep disgrace for any student to sell a text book after he has finished the course of instruction in which it was employed. If he does so, he is very liable to regret it for many a year. No books can quite take the place of those which one uses at college, even if much better treatises are later available. One's text books should be his friends as long as he lives—and it cannot be denied that it is bad policy to part with a friend!

DISTINCTIONS

The establishment of scholastic distinctions that has taken place mainly in the last quarter of a century is a move in the right direction, notwithstanding anything that may be said about its being *infra dig.* for one to work for grades and place. Any incentive to mental effort is a good thing; and college distinctions are appreciated in after years, as is evidenced by the prominent manner in which many gray-haired old fellows wear their Phi Beta Kappa keys. Such distinctions as those of that society, Sigma Xi, and Tau Beta Pi are eagerly coveted by students; and their possession gives to anyone a standing as a well educated man which cannot be gainsaid. The awarding of such distinctions might be carried farther than it is at present—for instance, by making Phi Beta Kappa available to engineering students who secure unusually good records in their literary courses. The effectiveness of distinctions to be attained is not by any means confined to college life—but this matter will be discussed later.

SECOND EPOCH

We shall now pass to the consideration of what can best be done by young engineers in order to advance the interests of the profession. The possibilities may be listed as follows:

1. Continuing study after graduation.

2. Buying books and collecting data.

3. Post-graduate work at some leading technical school, and obtaining of advanced degrees.

4. Joining technical societies.

5. Systemization of work.

6. Adherence to professional ethics.

7. Setting an ultimate goal to attain.

8. Writing technical papers and books.

9. Publicity of achievement.

10. Helpfulness to others.

11. Becoming a useful citizen, attaining prominence in the community, and keeping abreast of the times.

12. Studying the science of business and salesmanship.

It is now pertinent to make a short comment on each of these twelve ***desiderata.***

CONTINUATION OF STUDY

In respect to continuing study after graduation it may be stated, without any reservation whatsoever, that the man who fails to do so is the man who will not meet with any marked professional success—in fact he is not even likely to attain mediocrity. One can seldom do any piece of engineering work in the best possible manner without first learning how similar work has been done in the past; and to ascertain this he must read and study. One should not only peruse the leading American engineering papers, the Proceedings of one or more technical societies, and the principal new books in his chosen specialty, but also he should study such subjects as economics, engineering law, commerce and trade, and the general progress of science. If he has not already done so at school, he would do well to study the Spanish language; and in case that he has already a command of it, he should read enough Spanish books and papers to prevent himself from becoming rusty, besides practicing the speaking of it on every possible occasion. It is an excellent plan for the young engineer to keep up his mathematics by reviewing what he learned of the subject in his college course; but it will not be worth his while to continue it any farther, unless his work so require, because the mathematics given in any good technical curriculum are generally sufficient for the needs of the practitioner.

BUYING BOOKS

Every practicing engineer should purchase, as fast as they are issued, the various good engineering books, covering the lines in which he is specially interested, no matter how great may be the expense involved. A professional man can get along better without food than without books. He may not have time to read the entire contents of all that he purchases, but he should at least look them over so as to acquaint himself with their field and be able to refer to them when the necessity for so doing arises. A good serviceable technical library is certainly a most important asset for every practicing engineer.

POST-GRADUATE COURSE

Sometimes there comes to a young engineer, after he has been in practice a few years, an opportunity to take a post-graduate course; and he is truly a lucky man who encounters such an opportunity. One year of such instruction as he there receives is worth at least two years of the ordinary technical school course, partially because his practical experience has taught him the value of what he learns, and partially because he is so much better fitted by years and judgment to grasp and absorb the said instruction.

Next best to a post-graduate course is a year or two of teaching technical subjects in a high-grade institution of learning. Such an experience tends to make one exceedingly thorough in his work, especially the mathematical portion thereof. Too much of it, however, is not good; because it would cause an engineer to get out of touch with the practical side of the profession.

TECHNICAL SOCIETIES

Every engineering alumnus, just as soon as he receives his diploma, should hasten to join (in the lowest grade, of course) the national technical society most directly connected with his line of work; and if there be a local engineering society in the place where he resides, he should join that also. Through the national society he will come into touch with the great engineering problems of the times, and will make the acquaintance of many of the leaders in the profession, provided that he attends the annual meetings and conventions and, if practicable, the regular bi-monthly meetings also; and through the local society he will become interested in state and municipal questions involving engineering, all of which results are greatly to be desired. He should take as active a part as practicable in the affairs of his technical societies, and should make his services useful and appreciated.

SYSTEMIZATION

Systemization of one's work enables a man to increase his output thereof and materially to improve its quality. Again, when the time comes for the young engineer to write, his systematically kept records will enable him to produce something worth while.

ETHICS

The young engineer should adhere as closely as he can to the ethics of the profession; and, especially, he should avoid subjecting himself to the slightest suspicion of dishonesty or even sharp practice of any kind. An engineer's reputation is as delicate as a woman's, and if it be once really besmirched, it will be found next to impossible to rehabilitate it. The good things that a man does are often very quickly forgotten, but the bad ones are long remembered.

ULTIMATE GOAL

If each young engineer were to set for himself a professional goal to attain, and would strive to the limit of his ability to reach it, much good would result to both himself and the engineering profession, even if he should fail finally to arrive at the height of his ambition. If he will always bear in mind that there is plenty of room at the top of the professional tree, and will keep on trying to climb, he will attain results that would be unreachable without the spur of legitimate ambition.

TECHNICAL WRITING

Nothing will help a young engineer more than the writing and publishing of good technical papers and books, and nothing, except dishonesty, will injure his reputation more than issuing poor ones. Within a year or two after graduation an engineer can properly begin upon a small scale to write technical papers, provided that either he has something new of his own to tell, or that he collects and digests data of real value to the profession that have not previously been adequately compiled; but he should have a number of years of experience before attempting to write a book. The speaker's first book was issued nine years after graduation; and the reason that it was a success may have been primarily the fact that in those days (more than three decades ago) scientific engineering was in its infancy, or, truth to tell, unborn—especially the branch in which the speaker was then and still is specializing. Some engineers complain that there are too many engineering books on the market. That may be true enough; but, certainly, there are not too many good ones, nor can there be, unless they lack in originality or are mere copies from other works. The profession always needs good books for both technical students and busy engineers; because, as long as progress continues, literature can never overtake practice.

PUBLICITY

In respect to publicity of achievement in engineering, while it is certainly inadvisable for a professional man to make a practice of tooting his own horn, it is perfectly legitimate for him to use proper efforts to have his accomplished works and those of his friends and associates creditably noticed in both technical literature and the daily press. Moreover, such publicity tends to bring the profession of engineer into more prominence. All such notices, however, should be presented in a readable and interesting form which the general public can readily understand; unless, perchance, the subject be one that is altogether too intricate for the layman to comprehend, in which case the notice should appear only in the technical press.

HELPFULNESS

One of the greatest possible aids to the advancement of the engineering profession would be the inculcation in all its members of the spirit of mutual helpfulness. The young should go to the old for advice and assistance; but, on the other hand, they should be ready to help their elders in the investigation of problems, the compiling of records, and the systemization of data. Such joint effort and the mutual good will engendered thereby would be doubly beneficial, in that both the young and the old would be gainers and that their combined work would be serviceable to engineering. Again, the spirit of comradeship involved, if it were to become general, would certainly raise the profession to a higher ethical plane.

CITIZENSHIP

Every young engineer should try to make himself a useful citizen and a credit to the community in which he dwells, as well as merely a successful practitioner. If all engineers were to do their full share of the work in local politics and would take part in the leading questions and problems of the times, our profession would soon be much more highly appreciated than it is, and, in consequence, the nation would be benefited; because, on account of their technical and business training, engineers, as a body, are capable of more effective effort than the men in most of the other walks of life.

Every engineer, both young and old, should strive hard to keep abreast of the times by at least glancing through the daily papers, by reading such periodicals as the *Review of Reviews,* the *World's Work,* and the *Literary Digest,* and by making himself conversant with the latest important discoveries and developments in the various lines of science and art.

BUSINESS

A young engineer who will recognize that engineering is a business as well as a profession, who will study the principles of salesmanship and the science of general business in its broader aspects, and who will apply what he thus learns to his engineering practice, will improve greatly his chances for success in his life's work. By thus increasing his personal efficiency he will be doing his share towards increasing also that of the profession as a whole and towards educating the public to an adequate conception of its importance.

THIRD EPOCH

We shall now pass to the last division of the subject of this address, viz., what can best be done by the old, established engineers to benefit the profession; and as in the two preceding cases we shall list the possibilities as follows, recording them this time, as nearly as may be, in the order of their importance:

1. The establishment of an American Academy of Engineers.

2. Distinctions and rewards for effective and important services.

3. Acting as advisors to the American Government.

4. Aiding to pass proposed legislation that is favorable to the engineering profession and to prevent all that is unfavorable thereto.

5. Establishment of a clearing house for the employment of young engineers as well as of older ones of minor grade.

6. Improving engineering education.

7. Improving engineering literature.

8. Bringing engineers into closer touch with capitalists.

9. Securing for American engineers important appointments in foreign countries.

10. Placing road-building under the control of engineers

11. Placing city planning in the hands of engineers.

12. Placing municipal management under the jurisdiction of engineers.

Comment is now in order concerning each of these listed possibilities.

AMERICAN ACADEMY OF ENGINEERS

It has long been recognized and often remarked, in both conversation and print, that none of the American technical societies fulfill all the functions of which they might be made capable. Each society falls short of certain of its possibilities of achievement and usefulness. It was only as short a time ago as last October when the well known consulting engineer and technical writer, Mr. Ernest McCullough, in an address before the Western Society of Engineers, which was reproduced in part by the *Engineering Record,* scored heavily the technical societies. His paper was entitled "Time at Hand When the Engineering Society Should Awake to Its Deficiencies." His principal complaint was that the leading societies ignore the young men, and do not give them a chance. This condition is one of long standing; and, to meet it, young engineers in numerous cities have organized technical clubs and societies which do good work by bringing them together and giving them an opportunity to exchange experiences.

One of the essentials in which the national engineering societies fail is ethics. They have no adequate code therefor, and they make no systematic effort to enforce what little ethics they recognize, generally refusing to settle disputes among the members anent important matters of disagreement. A court of last appeal is certainly needed by the engineering profession.

Again, the national societies have not in the past made a practice of taking an active part in national and state legislation concerning matters of importance to the engineering profession, as certainly was their duty; nor have they caused their influence to be sufficiently felt at Washington in an advisory capacity in connection with important problems involving engineering.

Within a few years there has been established in New York City the American Institute of Consulting Engineers; and it is beginning to take action in legislative matters. However, on account of the close restriction of its membership to consulting engineers and the exclusion of all who are connected with contracting, it cannot well serve as a court of last appeal. Its objects, although indisputably good and worthy, are in a certain sense selfish, in that they relate mainly to securing compensation and recognition for both its own members and the rest of the profession. Its possibilities of accomplishment in certain lines are great, but in others they are *nil.*

Recognizing the necessity for a national engineering association of the highest possible standing, to be governed almost entirely by altruistic motives, and devoted to the advancement of both the engineering profession and the nation itself, certain engineers about the end of 1909 made a systematic endeavor to establish an American Academy of Engineers. The attempt was not a success at that time, but the idea of establishing the Academy has by no means been abandoned, for there may be started at any time a move to revive the project. The rock on which the enterprise split was the unwillingness of most of the projectors to run the risk of being considered by the profession and the general public as self-appointed charter members. Many schemes for avoiding the difficulty were decided and tried but were unsuccessful. As a last resort, it was suggested that President Taft be requested to nominate, unofficially however, the first twenty-five or thirty members, and let them enlarge the number to near the one hundred limit; but, unfortunately, the time of asking was too near that of the last presidential election, and after considering the matter for a week or ten days Mr. Taft very politely refused to grant the request. Since then most of the leading spirits in the movement have been too much occupied with other matters to make another attempt; but it is thought that President Wilson may be more interested in the enterprise than President Taft was, and an endeavor to bring the subject to his attention may be made ere long.

The objects and *modus operandi* of the suggested organization will be understood from the following quotation from its proposed constitution:

"Its objects shall be: To dignify and exalt the profession of engineer in the broad sense, and to place it upon the highest plane amongst the liberal professions; to bring the different branches of the engineering profession into closer touch and harmony with each other; to bring American and foreign engineers into closer relations with each other; and to secure for the engineering profession as a whole the recognition that is commensurate with the importance of its services to the world.

"It will strive to accomplish these objects by all proper, honorable, and legitimate ways and means; by fostering, stimulating, and encouraging the growth and development of the highest professional spirit, ideals, and ethics uniformly in all branches of engineering; by promoting a better understanding and sympathy between these different branches; by advocating more homogeneous and consistent rules and precepts for their guidance in their relations with each other and with the rest of the world; by working for general co-operation and solidarity; by fostering an *esprit de corps* in the profession as a whole, by doing all in its power to elevate the standard and promote the interests of the profession; and by urging its claims, or those of its more distinguished and eminent votaries, to due and proper consideration for public or private honor or recognition."

That great results can confidently be expected from the work of this proposed organization may be concluded from the type of men to be chosen for membership and from the interest in the movement which was shown. To give you some conception of the class of men who will belong to this association, the following further quotation is made from the proposed constitution:

"The qualifications of a candidate for Member shall include the following requirements:

"He must be a citizen of the United States of America.

"He must be at least forty years of age.

"He must have a degree from a University or Technical School of recognized standing.

"He must have a reading knowledge of at least one European language, or else of Esperanto, besides the English language.

"He must be a member in good standing, of the highest grade, in at least one national engineering or technical society in the United States of America.

"He must have practiced or else taught engineering, or some cognate branch of technology (such as chemistry) continuously for a period of not less than fifteen years, and he must be still engaged actively in practicing or teaching or both.

"He must have been in responsible charge of engineering or technical work or design for a period of not less than five years. If teaching, he must have been in charge of a department in a school of recognized standing for a period of not less than ten years.

"(In the case of candidates who have taught and practiced at different portions of their careers, two years of teaching shall be considered the equivalent of one year of engineering practice.)

"He must have been identified with work of importance either by reason of its magnitude or else because of its novel or special character; and it must be shown that he has made a satisfactory record and has obtained a good standing in his branch of the profession through his technical work.

"(In the case of a teacher of engineering or of technology, the publication of original books relative to his branch or branches of the profession shall be taken as the equivalent of engineering work.)

"He must be the author of at least one important original publication on some subject or topic related to at least one branch of engineering.

"He must have a personal as well as a professional record, reputation, and standing entitling him to the highest consideration as a professional gentleman who is devoted to the progress and advancement of the engineering profession and who is interested in promoting the welfare and sustaining the dignity of that profession.

"In general, the intellectual status of the candidate, and the personal traits or qualities making him a credit and an ornament to the profession of engineering, and, especially, his zeal and devotion to that profession, shall be the paramount considerations in determining his fitness. His financial status shall be of no consideration whatever.

"Any of the foregoing requirements may be waived in any particular case in behalf of a candidate otherwise very desirable; but the said waiver shall be only by the unanimous vote of the Board of Directors."

Two of the preceding clauses quoted from the proposed constitution set forth clearly and concisely the main objects of the contemplated association; but there are many minor or subsidiary objects, which were mentioned in an address by the speaker delivered at the first meeting of the projectors, from which address the following quotations are made:

"The augmenting of individual effort among engineers of all classes by setting before them in membership in this organization a goal to attain and a distinction well worth striving for.

"Such a result is the inevitable sequence of the materialization of our project—and it will come at once, without delay.

"The establishment of a court of last appeal in all matters relating to the profession.

"While our association, of course, could not properly suggest its services in this direction, the call will assuredly come; but it will take time to establish the organization as the natural means of settling disputed professional matters.

"The influencing of legislation, both state and national, to promote the development of the profession and to take action in worthy enterprises which involve engineering.

"If our association were to give its formal endorsement to any proposed measure, such approval would carry great weight in securing legislation; but extreme caution would have to be exercised in all cases in order to avoid endorsing projects of doubtful utility and those of a chimerical nature.

"The choosing of engineers for special services, both public and private.

"Here again our association could never legitimately take the initiative, but it would soon become customary, among those needing expert services and not knowing how best to secure them, to appeal thereto for advice. Such advice should invariably be given after due deliberation; and all decisions should be absolutely unbiased by personal leanings. Those most fit for the work contemplated should always be chosen; and where several names are recommended for the same position, it should be made clear whether all are considered to be of equal fitness or else what is the gradation.

"The extending of American engineering influence abroad, especially to the Latin-American republics.

"This object is one of exceeding importance, not merely to the engineering profession in the United States, but also to the Nation, for with the engineers will undoubtedly go trade.

"The inauguration of a code of ethics for engineers in general.

"No engineering society has yet been strong enough to establish such a code, but our association in time could succeed where other organizations have failed. It is an object well worth striving for, although certainly difficult of accomplishment.

"The exchanging of ideas with engineers of foreign countries.

"This could be done best through the honorary members, who should be encouraged to send yearly statements of the progress of engineering in general that has been effected in their respective countries during the past twelve months. One honorary member in each country represented should be appointed as a committee to report thus.

"Increase of compensation for engineers.

"Although at first thought this might seem a rather sordid object for our association to foster, it is really not so; because by increasing the value of engineers' services the public is impressed with the importance of the profession. In my opinion, we should employ every legitimate means to further this object.

"Improvement in engineering literature.

"By bringing into closer touch the practicing engineers and the professors of engineering and by encouraging them to work together on engineering literature, great improvements in its quality and scope could be effected.

"Encouraging of original research.

"Our association by giving its endorsement to any proposed investigation of a praiseworthy nature could aid greatly in securing the necessary financial aid therefor, either from Governmental or from private sources.

"Establishment of testing apparatus.

"An endorsement by our association of any proposed apparatus for testing any of the materials used in engineering would be of service in securing the requisite funds for its construction.

"Many improvements, reforms, and innovations would naturally be brought about through papers presented to the association; and in fact such presentation would be the most logical procedure to secure action on anything of the kind. To show you that there are numerous proper subjects for such papers, permit me to suggest the following topics:

"*1.* The Study of Foreign Languages in American Technical Institutions.

2. The Ethics of Engineering.

3. Latin-America as a Field for American Engineers.

4. China, ditto.

5. Africa, ditto.

6. How to bring American Engineers into Closer Relations with those of Foreign Countries.

7. How to Bring American Engineers of the Various Groups into Closer Relations with Each Other.

8. How to Avoid the Possibility of Disaster to all Great Public or Private Constructions.

9. Engineering Fees.

10. The Best Technical Books for Engineers in the Various Specialties. (This would be a series of papers or a combined paper by a specially appointed committee representing the various specialties in engineering.)

11. How Best to Enhance the Dignity of the Engineering Profession in the Minds of the General Public.

12. How to Improve Future Engineering Literature.

13. Engineering Degrees.

14. Expert Engineering Evidence in Courts of Law.

15. Punishment for Unprofessional Conduct.

16. Post Graduate Schools for Engineers.

17. How Best to Encourage Original Research in Engineering.

18. The Necessity for Great Testing Machines and Engineering Research Facilities, and How to Procure Them.

19. How to Improve the Methods of Inspection in the Manufacture of Steel Constructions.

20. What Should be Done to Develop American Shipbuilding?

21. Suggestions as to the Best Manner of Developing the Possible Water Powers of the United States.

22. The Advisability of Improving and Developing the Great Waterways of the United States.

23. How Best to Develop the Resources of Alaska.

24 How Best to Develop the Resources of the Island Possessions of the United States.

25. Improvement in the Teaching of English in Technical Schools.

26. The Needs in Engineering and Technological Courses of Instruction to Attain their Fullest Development.

27. How Best to Conserve the Supply of American Timber and to Economize in its Use.

28. The Conservation of the Coal Supply of the United States.

29. How to Bring Engineers into Closer Relations with the Pure Scientists.

30. The Extent to which Students in the Various Lines of Engineering Should be Taught Mathematics, and How.

31. How Best to Develop a Proper Enthusiasm for the Profession in Engineering Students and Young Engineers.

32. The Relations Between Engineering and Political Economy.

33 The Relations Between the Engineering Profession and Law.

34. How Best to Control and Limit the Pollution of American Rivers and Streams.

35 Engineering and Sociology

36 Engineering and Politics.

37 Aesthetics in Engineering Constructions.

38 The Study of True Economy in Engineering Designs.

39. The Relations Between Engineering and Architecture.

40. The Beautification of American Cities.

41. The Preparation of a Dictionary of Technical Terms used in American Engineering and their Equivalents in Various Foreign Languages.

42. How Best to Develop and Control the Irrigation of the Arid Lands of the United States.

43. The Preparation of a History of Engineering, either as a Whole or as Developed in the United States.

44. Smoke Prevention.

45. Uniform Engineering Terminology for English-speaking Countries.

46. The Furthering of Legislation Conducive to the Advancement of Engineering and of Public and Private Enterprise.

"This is a fairly long list of subjects, but it might easily have been made still more extensive. Enough topics have been enumerated, however, to show that there will be no dearth of matter to occupy legitimately the attention and energies of the members of our association.

"Some of you may have noticed that many of the topics proposed come under the scope of political economy; and it may be objected that such is not engineers' work, but with that objection I beg emphatically to differ. Political economy is a subject that can be treated only by men of years, learning, and experience; and what body of men can there be found so well developed in these lines as the members of our proposed organization? It is the engineers who make the world move, and who so competent as they to say in what manner it should be made to move? There is, in my opinion, no other class of men so well fitted as engineers to deal with questions involving political economy."

In the speaker's opinion, the formation and successful establishment of an American Academy of Engineers on the lines just indicated would do more to advance the interests of engineering in the United States than anything else that comes within the realm of possibility.

DISTINCTIONS AND REWARDS

In one important particular European and Canadian engineers have an advantage over their American brethren, in that the honor of knighthood is a goal to which they may attain; and this certainly acts as a wonderful incentive to their professional effort. It is to be regretted that there is no such institution in this country; for if there were, its effect would be eminently beneficial not only to our profession but to all the others. The difficulty would be to keep the organization out of politics. This might be done if the American Government were to start it and get it into good running order, then, relinquishing its authority, turn it over to its members and allow it to be self controlled. Some people will say that such an institution would be undemocratic and incompatible with the principles that ought to govern a republic; but such is not the case. Republican France has its *Legion d'Honneur*, to belong to which is the highest distinction any Frenchman can attain; and its influence is good. Again, England is really as democratic in most respects as the United States; and yet the British orders of knighthood constitute the highest reward for distinguished service throughout Great Britain and all her colonies. Knighthood is superior to all other titles in that its possession ceases with the life of its owner, and that it cannot be disgraced by passing to a vicious or semi-imbecile son. It is certainly a fine institution, stimulating men to worthy thoughts and deeds and keeping its members in the straight and narrow path of integrity and justice. Notwithstanding what is said against it at times in this country, it is a fact that very few American citizens have ever rejected a proffered foreign decoration, and it is true that those few here who have received such honors value them more highly than any American distinction attainable. It seems belittling to have to confess that about the only recognized distinction in the United States is the possession of the Almighty Dollar, but that is indisputably the case; and generally the public does not inquire at all closely into the ways and means by which it was obtained.

Democratic as any country may be, it always has an aristocracy of some kind, be it only that of wealth. The true aristocracy, however, is neither that of birth nor that of money; for it is the aristocracy of brains combined with integrity—and the world is fast coming to appreciate the correctness of this statement. In the speaker's opinion, in two or three more generations it will be the only kind of aristocracy recognized throughout the world. Aristocracy based on heredity is always unreliable and often farcical, while that based on mere wealth is disgraceful. Why should any man be honored above his fellows merely because his father held a hereditary title, or because either he or some ancestor of his was shrewd enough to amass a great amount of money? But if, on the other hand, distinction were based solely upon personal achievement, its possessors would be truly worthy of the respect that would be conceded to them by the public.

Although it may not be feasible at present for American engineers to aspire to the honor of knighthood, as do our technical brethren to the north of us, it would be practicable for the profession to establish a few truly American distinctions which would be appreciated by their recipients more highly than any foreign decoration, and which would be recognized willingly and cheerfully by the general public. The late Alfred Noble was affectionately termed by some of his professional friends the "Dean of American Engineers," and he truly deserved the appellation. Now why cannot such a title be established as an actuality and conferred as a life-holding by a joint vote of all the national societies and other American technical societies having a certain minimum membership? The possessor of such a distinction would feel prouder of it than of being elected president of the United States, because in his case the honor would be an award of merit, while in that of the presidency it might be such, and again it might not.

Similarly there might be elected deans of all the recognized technical societies throughout the country; and by forming guilds of the various engineering specialties, there could be elected a dean for each guild. In this manner many worthy men would be distinguished by their professional brethren and recognized with respect by the laity.

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The inauguration of such a system of distinctions could best be undertaken by some powerful engineering organization that is not included in the list of national technical societies, such, for instance, as the Engineers' Society of Western Pennsylvania. The speaker respectfully commends this subject to you as being worthy of serious consideration. The establishment of such a series of distinctions undoubtedly would involve considerable labor; but the fact of having materialized it would be a great honor and credit to your society.

ACTING AS ADVISORS TO THE GOVERNMENT

Owing to the short term of office established by long-existing custom for the administration at Washington and to the consequent continual changing of its personnel, that body is constantly in need of expert advice upon subjects that are of importance to the welfare of the nation—and what member of the community is there so capable of giving it as the expert engineer? Were more of our leading engineers called into consultation by the national government, it would be far better for the welfare of the republic. Engineers as a body, working both individually and through their organizations, should endeavor to make the influence of the profession felt in national affairs.

LEGISLATION

While log-rolling and wire-pulling at the national and state capitals are distasteful to many good men, a certain amount of such action is unavoidable in order to introduce and pass worthy acts and to oppose those which are unworthy. Utilizing influence at a capital with the government and its advisors can be done in a perfectly legitimate manner, and there should be no reflection made upon any man for so doing, provided that he does not transgress the rules of right and fairness. Moreover, the speaker can see no sound logic in anyone's raising objection to the employment of a specially trained lawyer to aid him in such work; because existing conditions at capitals render expert advice and assistance necessary, if one is to succeed in his dealings with legislatures.

While on this subject it is apropos to mention the question of the licensing of engineers by the state governments. This is a movement to which the speaker is fundamentally opposed. If there is to be any licensing at all, it should be done by the Federal Government; and any license issued should permit the holder to practice in any portion of the United States or of its tributary possessions. Moreover, any graduate of a technical school of recognized good standing should be given his license without passing an examination; and this remark applies specially to men of years and experience, for many of the recognized leaders in engineering would fail utterly to pass an examination which would appear to be quite easy to a recent graduate from a technical school. Although the speaker spent six years of his professional career as a teacher of engineering, a part of that time in its most abstruse and difficult branch, viz., rational and technical mechanics, involving constantly the employment of all the ordinary branches of the higher mathematics, he must confess that today he would fail utterly if he were required to establish some of the principal mathematical formulae, even in algebra. It is not fair to ask a practicing engineer to pass a school-boy examination.

As far as the exclusion of undesirables from the practice of engineering is concerned, licensing would be a good move, but no state has any moral right to prevent non-resident engineers of ability from doing work within its boundaries without first passing an examination and paying a fee for a license. Such action is carrying states-rights too far. We can easily have in this country too much of states-rights for the country's good!

CLEARING HOUSE FOR EMPLOYMENT

Some of the national and other technical societies from time to time have made half-hearted attempts to provide work for their unemployed members; and there are numerous employment agencies which often for an excessively large pecuniary consideration accomplish that purpose; but there is need for a great clearing house for engineering services, run upon the cooperative basis and on economic lines. Such an organization has been much talked about of late, and has been discussed in the technical press. It is earnestly to be hoped that success will attend the efforts of those promoting the worthy enterprise. In the speaker's opinion, it will require the cooperation of a number of engineers of established reputation in various lines of work with the great mass of the recent graduates and the rank and file of the older engineers who work for an uncertain wage, in order to materialize the contemplated organization. Good luck to all who are interested in this important and altruistic undertaking!

IMPROVING ENGINEERING EDUCATION

Practicing engineers, as a class, are remiss in their duty to the profession because of their failure effectively to cooperate with the faculties of the technical schools in their endeavor to improve their courses of instruction. The Society for the Promotion of Engineering Education, one of the most worthy of all the American technical societies, should have on its list of members the names of more practicing engineers; and these should do their proper share of the work of the society by attending its annual meetings, taking part in the discussion of its papers, and serving on its standing committees. Each successful engineer owes a debt for his education, not only to his *alma mater* where he received instruction that cost the institution in hard cash far more than the tuition fees which he paid, but also to the profession through which he has earned a living for the support of himself and his family. It, therefore, behooves him to give somewhat of his time, energy, and money to the support and development of the technical schools of the country, to the end that worthy recruits for the profession may be properly trained to succeed him and others like him in carrying on the great work of engineering and in raising the standing of our profession to the plane which it ought to occupy.

There is a crying need for more and better post-graduate schools for young engineers in all lines; and the practicing engineers should do their utmost to aid in the establishment of such schools. It will not do, though, this evening for the speaker to begin riding this hobby of his, as time will not permit; suffice it to say that, if any of you desire to know his views in detail on the subject, such curiosity can be satisfied by reading a paper entitled "Higher Education for Civil Engineers," which was included in Mr. Harrington's collection of the speaker's "Principal Professional Papers" and in Waddell and Harrington's collection of "Addresses to Engineering Students." The importance to the profession of the establishment and utilization of such post-graduate schools cannot well be exaggerated.

IMPROVING ENGINEERING LITERATURE

The importance to the profession of good engineering literature has already been touched upon this evening; but it is pertinent to remark that every successful engineer should leave, for the use of those who are to follow him in his specialty, some available record of his life's work and of the special knowledge which he has amassed through his investigations and his practical experience. The speaker is now completing such a record of his findings and accumulated data; and although the amount of labor involved was stupendous and the unavoidable financial expenditure abnormally large, he feels that he will be well repaid for his efforts and for the money invested, if in no other way, by the satisfaction of leaving behind him, when he passes on, a treatise that will effectively help, for several decades to come, the young practitioners in his specialty.

ENGINEERS AND CAPITALISTS

Without capital for investment there would be no engineering, and without engineering there would be very few opportunities for capitalists to invest their money; hence it behooves capitalists and engineers to get together as closely as possible and to work in harmony. Capitalists today certainly employ engineers to aid them in making their investments; but they are prone to look upon such experts as merely hired men; and too often they deal with them as such, while they ought to treat them as associates and should share with them in the profits of the investments made through their advice, which, to be of value, has to be backed by many years of experience. Engineers should make a point of insisting upon receiving a fair share of the profits from enterprises that are materialized and made successful mainly through their skill, experience, and hard work.

SECURING FOREIGN ENGINEERING WORK

Until quite lately American engineers have been kept almost exclusively occupied with the development of their own country, leaving European engineers to attend to that of the Latin-American republics, Africa, and parts of Asia; but the times have changed in this respect, and it is now advisable for American engineers to look abroad in search of a field for their endeavor and for opportunities to employ their energy and skill. The countries which, because of their geographical position, we should naturally exploit are those of Central and South America, but Russia, with its great Siberian field to develop, should not be overlooked; and the whole of fighting Europe after the war ceases will have much repair work to perform. Perhaps American engineers may be needed to help therein, because the death-toll in the great war has been specially heavy among the engineers, and, in consequence, Europe may find itself handicapped for want of expert men to direct the reconstruction of its damaged properties.

ROAD BUILDING

The United States today needs good roads more than anything else in order to develop its productiveness and its commerce. Until quite lately road construction has been left almost entirely to incompetent, ignorant, and, too often, dishonest county commissioners and road supervisors, with the result that much money has been spent and bad roads have been built. A few of the states have just awakened to a comprehension of the fact that road-building is engineers' work, and should be entrusted to them only; but in most of the states the same old, extravagant, absurd, and dishonest methods of handling the road problem still exist. Engineers throughout the entire country should insist that the road building be left to the members of their profession. Concerted action on their part will eventually accomplish this much needed reform.

CITY PLANNING

The laying out of American cities in the past has been done mainly by haphazard methods; and it is only of late years that any scientific city planning has been effected. Such work belongs to the engineering profession, and should be done by no one else. It is up to the engineers of the large cities to see that this class of work is given to civil engineers.

MUNICIPAL MANAGEMENT

It is hard to conceive anything more unscientific, more uneconomic, or more glaringly absurd than the usual method of expending city finances. This is because the responsibility therefor has been left in the hands of a horde of politicians, whose main object generally has been to feather their own nests, with the result that the work of both development and maintenance has been wretchedly and dishonestly done, and that city politics has become a by-word of the nation for all that is rascally and crooked. The first attempt to cure this crying evil was to establish the commission form of government; but the result was only partially successful, because responsibilities were divided, services were either given gratis or were underpaid, expert men were not chosen, and corrupt politicians were occasionally appointed. The correct solution of the problem is the employing at adequate compensation, of a competent "City Manager," who invariably should be an experienced civil engineer, freeing his position absolutely from the control of politics, letting him choose and hire all his help, and holding him strictly responsible for results. It is claimed that this method puts too much responsibility upon one man, that it gives him autocratic power, and that it affords him an opportunity to amass wealth dishonestly at the expense of the community. All this may be true in theory; but it must be remembered that engineers are accustomed to shouldering great responsibilities, that one-man power is the most effective of all kinds to accomplish results, that there are very few dishonest engineers, and that the prominence of the man chosen and the publicity of all his operations would surely keep him from becoming corrupt.

It was the speaker's intention in closing this address to present a short summary of the most important points that he has raised therein; but its duration has already far exceeded the time limit that he set for himself when he began its preparation; hence the summary will have to be omitted. Instead, there is offered an earnest appeal to all the members of this energetic engineering society to read and consider carefully at their leisure the various suggestions that have been made, and to try both individually and as an association to effect the accomplishment of at least a few of those that are of primary importance to the profession of engineer.

DISCUSSION

DR. F. L. BISHOP:* (Member). Dr. Waddell has stated so many truths in such an acceptable and pleasant manner that it seems impossible to make comment on any of them. I thought, as he was reading his excellent paper, that we should judge engineers by engineers and not by lawyers, and certainly if we judge engineers by Dr. Waddell we find that the engineers stand preeminent.

I could pick out from his address a hundred or more points, any one of which I would like to comment upon, but I have noted down two or three points which, perhaps, I can deal with in a slightly concrete manner.

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*Dean, College of Engineering, University of Pittsburgh.

I think there is a very marked tendency at the present time for the Federal Government to consult with engineers. I have had the pleasure recently of serving on a committee of five—four eminent engineers and myself—in connection with the Navy Department, and I was very much surprised and pleased to find how anxious and eager the officers of the Navy were to secure the advice and co-operation of civilians. It was entirely opposite from what I thought existed in the Navy.

In the matter of research, Pittsburgh should stand pre-eminent. Dr. Waddell, I think, will agree with me in saying that Pittsburgh is perhaps the center of engineering industries of this country. The greatest research laboratory should be located in Pittsburgh. It should be controlled not by academic investigators but by men who have seen years of experience in the greatest of engineering industries, who know the various types of problems which should be investigated and the manner in which these investigations should be carried out. If I have one aim while located in Pittsburgh it is that some day we may see erected the largest, best equipped,—I mean primarily in matter of brains—engineering research laboratory in Pittsburgh, that there is in the world, and I am sure that it is going to be forthcoming.

There is, I think, to be appointed by, or started by, the Society for the Promotion of Engineering Education, a joint research committee. I might say, for Dr. Waddell's information, that this is not outside of the Secretary's office to any extent, but I am in hopes it will be worked out at the next meeting of the Society. The Institute of Electrical Engineers is at the present time attempting to work out something along that line, and I am sure that many of you will receive letters, as members of the Educational Committee of the Institute, asking you to state specific problems which you would like to have investigated, problems that can be turned over to young instructors, or as a subject for thesis. Those problems, practically all of them, will have to be simple, but we would like a long list of problems which would be suitable for that type of work.

Dr. Waddell and myself disagree as far as the North Pole is from the South Pole in regard to the five or six year engineering schools. The only trouble with them is—they have excellent schools, two or three of them in this country—they don't have any students. There are supposed to be 122 engineering schools in this country.

The book that Dr. Waddell was so kind as to prepare for the use of engineering students, I may say to him, has been very acceptable. We have used his book, and it is so good that the students found that it was like making a whole meal out of ice cream, so we had to use his book, not continuously, but occasionally, and I imagine that is the way he intended it should be used.

Dr. Waddell has advocated Spanish. If you wait long enough most anything will happen that is interesting, and it is happening in engineering schools. While most of them require one or two years' study of a foreign language the students are gradually swinging over from German and French to Spanish.

MR. JOHN A. FERGUSON:* (Member). At first thought it would seem useless to try to discuss a paper so thoroughly prepared as this and one which covers in so admirable manner all of the subjects which might ordinarily be discussed by engineers when considering the subject of the advancement of their profession.

In my opinion, one of the greatest difficulties of engineers is due to the fact that they do not get down to a true statement of the case. They usually begin a discussion of any subject by mentioning all of the details to which they can draw attention, and go through the presentation of a paper or article without having classified or emphasized the main thoughts. Almost all of the time engineers attempt to discuss the detailed side of their work with persons not qualified to understand such subjects, in the hope of thus impressing them, and all the while missing the main thing they desire to know, and that is the connection between what the engineer knows and what they know, and what can best be done to bring them together for an effective solution of business problems which are affected by the work of the engineer.

Certain portions in this most excellent paper have led me to analyze the membership of the Engineering Profession in the few

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minutes since allowed to me for thinking and group it in three classes, as follows:

1. The rank and file.
2. Those attaining eminence.
3. Those having attained eminence.

The subject of the status of the individual members of the profession being thus grouped leads one immediately to study what sort of thing has led or forced men out of one group into the one next higher. A clear understanding of the problem of those who leave the rank and file, and of that which led them up and out, will do much good toward pointing the way to the advancement of the profession in general and encouraging its individual members to better successes. This last will be concurrent with the advancement of the profession as a whole.

Common observation shows that the rank and file of any profession learned to do well what they were told, never attempting to think out what bearing their duties have upon the business transactions of which their task is a unit; neither do they set themselves to the task of so performing their work and studying up its connection with the business interests which they serve that the business employer will naturally see that they have been of the greatest assistance to him in solving his problem.

Invariably that engineer is put in charge who knows not only how to do the work of the men of the rank and file, but how to direct the work in such a manner that the business necessities and connections therewith will best be served.

It must be remembered always that the matter of stresses and strains, or of tests in materials or machines, or of the mathematical analyses employed, or the many other paths which the engineer must tread, are not the sole end and purpose of his existence. Somewhere, somehow, men must be found who can so plan and direct the performance of these briefly enumerated duties that it will pay in money and otherwise to have them performed. No industry will thrive upon the sole principle that it is necessary to perform such duties as above enumerated alone. It is necessary that all matters with which the engineer is connected be financed. Those industries succeed best which are the best engineered, of course, but in order to engineer them well the work of the engineer must be done with reference to the needs of the industry, rather than with reference to the performing of the individual subordinate tasks. That engineer who can co-ordinate and arrange all the work, being done, for the advancement of the business enterprise, so plan and scheme it that it will be done well enough to bring about the end desired in the speediest and least expensive manner is called the Executive Engineer, is paid the most for his time, is given the greatest responsibilities, not even second to the financier who must provide the money. Consequently when those who provide the money have been clearly shown that such is the case, and how much they depend upon men of this character, they will pay the proper amount of recompense to the man who can force them to see the necessity thereof by the simple presentation of all related subjects briefly, accurately and in a business manner, and they will not need much convincing when the balance sheets for cost show what has been or can be done for them.

Under the modern growing and broadening conception of the status of the engineer in our country we have not stopped long enough to analyze clearly the problem before us, and to test this problem for its principal points, or to arrange them in their proper order and state them briefly enough so that they will remain always before our minds in a distinct and forcible way and keep the discussion of such subjects as this from going beyond their proper bounds and also to make them effective. It is well then to state what we expect of an engineer nowadays: It is expected of the engineer attaining eminence and having attained eminence in his profession that he will be able to undertake almost any task which can be allied to the principal division of the profession, analyze it clearly, sub-divide it into its principal divisions, arrange in their proper order the sub-division matter, at the same time obtaining all information and light possible on the subject, and after careful scrutiny remove that which is not pertinent, retaining only that which will be of service, and then, and only then, proceed to the performance of the task with a special view to the thing which must be done and the service intended to be performed to the business interests and its influence upon the results of the business interest itself.

As it will thus be seen, engineers must get to be business men if they expect to attain eminence in their profession, and they must present to business and financial men clearly, succinctly and briefly the advantages to be obtained by their employment and the employment of the highest and best professional men commensurate with the task to be performed and the actual economy of so doing. Common observation will teach us that nobody is going to be looked upon as successful in his undertakings unless he pays his way, be his interest what it may.

Another thought which is interesting in connection with the problem of advancing the Engineering Profession and the welfare of its individual members is the matter of interest in public affairs. Engineers as a rule are clean men. Their training and the teachings of their profession tend to produce this effect. Most engineers are aspiring men, else they would not have undertaken to go through the rigors of training and the conduct of their profession thereafter. Consequently it is my belief that the engineering profession, both during periods of training and afterward, should show its members the advantage of taking a distinct interest in public affairs and the management of their Government, with especial reference to the matters pertaining to their profession. Mr. Alfred Noble, who held the title of Dean of Engineers in America, once told me that he would advise young engineers to devote a certain period of their early life to the performing of public work. I understood him to say that he owed his start away from the rank and file to the fact that he was in such a position that the public could observe the excellencies in his work. If engineers will take up public work for the first few years of their career and seriously endeavor to put every one with whom they come in contact upon the same plane of endeavor as themselves, it stands to reason that much will be done toward creating the highest form and the cleanest, best and most efficient administration of public affairs, connected with this most dignified profession, and thus they will have done one of the most important things which can be done to bring to the public the advantages of the engineering method of doing work and increase its appreciation thereof.

Mr. F. N. Speller:* (Member). For three years the Committee on Engineering Education of this Society has been setting problems which are open to competition among the students in the junior and senior classes of engineering schools. Last year one problem was set in each of the fields of sanitary, mechanical, electrical, structural and metallurgical engineering.

The object of the competition is to promote engineering education and in particular to co-operate with technical institutions in developing in students the practical qualities essential to success in engineering work. These problems are submitted to judges selected from men of the highest engineering standard in this community.

Certificates of first, second and third awards are given in each of the fields in which the problems are set, with a number of honorable mentions. The solutions given awards are exhibited in the rooms of the Engineers' Society of Western Pennsylvania and the names of the recipients of the awards are published in the Proceedings of the Society and the engineering press.

The response has been quite general—over two hundred having entered the competition last year. We have welcomed criticism and suggestions. There has been criticism from only one or two of the technical schools, the main point being that the faculty for some reason have received the impression that the Engineers' Society was treading on the prerogatives of the schools in attempting to set problems to be worked out in connection with the course of instruction; i. e., they took the view that the student is in school to learn simply the rudiments and scientific foundation of engineering and that the faculty were best qualified to set and judge problems for students. At a matter of fact, the main object of these problems is to bring the student in close touch with such problems as he may have presented to him when he starts to apply the knowledge acquired at college in earning a living. He is allowed to use his discretion as to the sources of information required in the solution of the problem; he may seek this information just as he would in practice by consulting technical works, discussing the matter with his professors or others, or writing letters to those who may have had special experience in line with the problem. In short, he may employ any honorable means which will enable him to work out for himself a successful solution of the problem.

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*Metallurgical Engineer, National Tube Company, Frick Building, Pittsburgh.

MR. SAMUEL E. DUFF:* (Member). I want to take up for discussion one phase of Dr. Waddell's paper, which appealed to me. I refer to the organization of the American Academy of Engineers. There are some things in Dr. Waddell's reference to it which appear to me to be particularly important for discussion before this Society.

I notice that membership in the Academy is to be restricted to members of what are called the National Engineering Societies.

It seems to me that the organization of engineering societies in this country is fundamentally wrong, and for one particular reason; viz., the National Engineering Societies of this country are divided into societies largely of specialists. I think that principle is fundamentally wrong.

If we are ever going to reach a National Academy of Engineers, I rather believe the probability of the structure of the Academy being carried out along the lines on which this Society is organized and managed, viz.; all branches of engineering combined on practically an equal footing as far as the membership and management are concerned.

We have in our Society, Sections for the discussion of the separate branches of engineering, each particular branch in its own way. We are not able to carry that out, possibly, as extensively as we will later. In other words, sometimes the discussion before the Structural Section of the Society may not be restricted to structures only, and the same way in the Mechanical Section, a subject possibly not restricted to mechanical engineering may be discussed.

But in the majority of cases, each section takes up its own work.

It seems to me perfectly feasible to organize in the United States a series of local societies similar to the Engineers' Society of Western Pennsylvania, working on their own local and definite problems, with which they are extremely familiar. It is also possible to fix the qualification for full membership in these societies by some national convention or other means for national agreement, and it is also possible to set the standards of ethics of the profession by similar national agreement, leaving the local societies to manage their own social affairs and their business affairs in a large degree by themselves.

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I believe this is the only feasible way to organize on a practical and permanent basis a National Academy. In such a way, the important things which Dr. Waddell has so carefully mentioned could be most easily and surely brought about, viz., the fixing of a standard code of ethics and the enforcement of that code. something very difficult to do from a remote spot, rather than through the agency of a local society which can become entirely familiar with the case in point, and the matter of taking care of the young engineer, of fixing his status, his remuneration, etc.; things which can best be handled by local management.

In the same way, employment, or any altruistic matter which it may be advisable for engineers to take up, education of the public on engineering subjects, etc., are best handled by taking into account the local conditions, rather than attempting to establish standards suitable for the whole country.

One other point that I want to speak of in Dr. Waddell's paper is the length of time a student should remain in an engineering school—the six years that he speaks of. This is something I have no right to talk on because I am not an educator, but it seems to me that one of the difficulties we have today is that a great many of the younger engineers go to school too long in the sense that they follow too long a multiplicity of detail in engineering education without the practical experience. I have had a little experience with some graduates of schools who are filled full of such a mass of detail that some of them have forgotten the fundamental principles, and if you happen to get on the line that they think they are going to be specialists in, they will bore you to death with a lot of infinitesimal detail that the practicing engineer, who has to satisfy capitalists and get something done, hasn't any time to listen to. I think one can go to school too long. I think that Dr. Waddell's suggestion of an engineering course of six years should be modified to some extent so that practical work is taken up sometime during that course. I think the great defect the engineering graduate has to overcome is that he has not had any definite connection with commercialism, or business, or the fact that everything must be done at a profit—he lacks the connection between that fact and his technical education.

MR. EDWARD GODFREY:* (Member). Dr. Waddell has mentioned the fact that we need engineers to take an interest in the matter of research.

Some months ago the Bureau of Standards, of Washington, notified concrete engineers—all the way from Boston to St. Louis—to advise with them on the matter of making tests on reinforced concrete. They seemed to want the government to make an appropriation for a large testing machine costing something like a half million dollars.

The speaker made the suggestion that, instead of a large testing machine, a great deal of useful data could be obtained by the government building sample buildings and actual structures and loading them with pig iron or water or by any other practical method.

The trouble in this country is that the investigation of reinforced concrete is too much in the hands of commercial interests. An inventor of a system builds up a test to satisfy himself, and intepretes that test to satisfy himself, and that information goes into technical literature as engineering information. If an owner of a patent medicine should try his medicine on an alleged sick dog or monkey, and then write that up in a medical journal, it would correspond with a great deal of the so-called technical information that we have in our engineering papers that is gotten up purely to prove the benefit of some re-inforced concrete system. These tests are not controlled by engineers and are not interpreted by engineers. The matter is not engineering, and yet it takes a place in our engineering literature. It seems to me that engineers should take over this matter and should give no recognition to anything that is not unprejudiced, unbiased engineering investigation. There is a great need of that because structures are failing, due to the fact that they are not designed properly or correctly, particularly reinforced concrete structures. Engineers should look into this thing and claim their rights to dictate what is engineering.

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*Structural Engineer, Robert W. Hunt & Co., Pittsburgh.

MR. RAYMAN: While I believe that most engineers are idealists to a certain extent, it has come to me through some years of experience that most men of business appreciate the man according to what he costs him. Therefore, the matter of compensation is one of the most important phases of the subject. Not long ago a friend of mine, who is manager of the sales department of one of our large concerns, said to me, "You can always buy brains cheap." And he is right. You can always get brainy men cheap if you go after them. And it seems to me that the only way by which the engineering profession—or one of the principal ways—can make itself properly felt is to force better compensation.

PRESIDENT SAMUEL E. DUFF: I am going to ask Dr. Waddell to reply to the discussion, if he cares to, and close up the discussion. Although we do not want to stop it, I believe many of you want an opportunity of hearing Dr. Waddell again, and many have to leave on account of trains.

Any further discussion we can have after that, and we wish to announce also, as we always do on occasions of this nature, that the Society welcomes written discussion. It often happens that written discussion is more valuable than oral discussion, especially on a paper of this kind, which is so extensive that it is difficult to take it all in in a moment. We would like, therefore, to have all the written discussion of this paper any of you care to submit.

DR. J. A. L. WADDELL: Well, you have said just what I had in mind. That is, I should like very much to have you all take part in the written discussion of this paper. To do any good the paper must be thoroughly discussed. The best part of a paper is generally the discussion—the most effective part—and very often the discussions are far better than the paper itself. I should like you all to think over these various points that I have brought out and treat them thoroughly.

There is just one little point in connection with my paper I should like to mention—and a rather peculiar one. I finished it coming east about ten days ago on the train, and on the way back I revised it. There was a young man—a bright-looking fellow—sitting nearby me; and after I got through he joined me and stated that I had more energy than he, that he had a job like mine which he ought to have done on the train and didn't do. I asked him a few questions about himself and found that he was an engineer—a graduate from Illinois. I handed him the paper I was preparing and told him he might look it over, if he liked, without intimating to him what it was. He spent an hour or two reading it over, and when he got through he said, "I don't agree with you." Consequently, I asked him to be present at this meeting to discuss the paper, for he said he might be in the east about this time. The point of disagreement was this: He stated that he had gone into engineering work without making any marked success, hence he concluded that it doesn't do to hold up too high ideals to engineers because of the great disappointment that must generally happen later. He said for years he had "hitched his wagon to a star," and in so doing he had failed; then had had to go into business.

Now, I don't look at the matter in that light. I think we ought to strive for the best results, and if we do not reach them we will be the better for having striven. Perhaps I am wrong in holding up too great ideals, but I don't think so. That is for you gentlemen to discuss. The young men can talk on this, perhaps, better than the older ones. For my part, I have always worked for the profession; and I should like it to be raised to the highest possible plane. I don't expect it to reach there during my lifetime, but do expect to see it raised somewhat higher than it is at present.

I should like to have your worthy discussion put in writing. This Society is a powerful organization, and can do a great many things that the hide-bound national societies cannot do. Let me state an instance. The American Society of Civil Engineers will not settle disputes. That is not right. There should be some society to settle disputed professional matters among civil engineers. I know of a case very close to me, for it concerned one of my old men. He had gotten into a wrangle with a professor who had done some work of his and they had disagreed. Each honestly thought he was right, hence they passed the question over to the American Society of Civil Engineers for settlement, but that society refused to give any opinion. That is one reason why this movement for an American Academy of Engineers is desirable.

By the way, Mr. President, you did not get a correct idea of the proposed Academy. It is not to be an adjunct to any of the national societies. The members are to be chosen from men who have made good, from men who are working for the profession as a profession, from men who have no axe to grind—those who have arrived, in fact, and who want to help the others; and the members are to be limited to one hundred, at least for a few years. It is intended to be something like the National Academy of France; and the members are to be chosen from all branches of engineering—military, civil, electrical, mechanical, chemical, etc. Those men were to get together and do their best for the engineering profession and for the United States. That was the idea; and I think we shall eventually succeed in organizing such a society on those lines. A great many of our objects would be covered by the society that your President suggests, and it is, of course, possible that his may be the better way.

Now, if there are any questions you wish to ask me in connection with the remarks I have made, I shall be very glad to answer them if I can.

Mr. A. Stucki:* (Member). This paper looks to me like a beautiful brooch having a great many jewels—diamonds if you like—and there is one little stone which was mentioned, but it shines out very brightly, and if Dr. Waddell had not said anything else we would all be repaid for coming here. The point is in regard to the capitalist; when he said that the capitalist should consider the engineer not as an employee, but as an associate. Gentlemen, there is a great deal to think about in that comment.

This brooch will keep on shining, and we, the Society, should give a rising vote of thanks to Dr. Waddell for delivering his paper. Mr. President, I make that motion.

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*Consulting Engineer, Oliver Building, Pittsburgh.

The motion being seconded, a rising vote of thanks was given Dr. Waddell for his paper.

CORRESPONDENCE

PROF. JOHN H. LEETE:* (Member). It is a matter of deep regret to me that I was unable to attend the meeting at which Dr. Waddell's paper was presented and to hear the discussion of the paper at that meeting. After reading the paper carefully, I find myself in agreement with the writer upon his main points, but the shortcomings of the engineering profession, though they are deplorable beyond doubt, do not seem worse than should be expected at this stage of its development.

Moreover, I am not overly impressed with the inadequate compensation awarded the services of an engineer—possibly this is because I myself am a member of the teaching profession.

I shall confine my discussion to one or two points suggested by Dr. Waddell in his treatment of the first of the three epochs in the life of an engineer, viz., the period devoted to training in the technical school. I am quite willing to admit many of the faults ascribed to the school, but it does seem that even five years is somewhat too limited to accomplish all the desirable results asked by the paper. Isn't it possible that some of these finalities should be developed in the home,—or at least that the school should not be charged with the entire responsibility of development of habits and character?

Take, for example, the very desirable results named by Dr. Waddell, the inculcation of a love of study and work for their own sake and not mainly because of the money that can be earned thereby; or the accomplishment of better results in the use of correct English; or the liberalization of the technical course through cultural subjects. In all these things it is difficult for the school in the limited time available to overcome the outside influences which operate on the mind of the student. We all know how prevalent is the opinion that success and happiness (?) are gauged by money returns; that a double negative or a split infinitive is of no importance, provided the calculations and deductions are correct; that to study foreign language or history is a waste of time for the engineer—why, there have even been criticisms as to the value of teaching certain portions of the calculus which are not thought to have very direct application to practice

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Against these opinions and in spite of unfavorable home and industrial atmosphere, the teacher has fought a courageous but not always successful battle. It is encouraging to have a great engineer express such sentiments as are found in this paper and to realize that his attitude is gaining favor in the minds of the engineering profession at large.

In my opinion nothing would be more helpful toward accomplishing better results in all of the three directions under discussion than the preaching of Dr. Waddell's gospel to the undergraduate student. It is not so much a change in courses of study or of methods of teaching that is important as it is a change of attitude on the part of the student. If he can be made to realize that English and cultural studies and general scholarship are as vital to him as mechanics and laboratory practice, the rest will be comparatively easy to accomplish. I would not, however, have English and cultural subjects taught from the bread and butter standpoint, as Dr. Waddell seems to suggest, but would have the student study them for their own sake—for the broadening and enriching of his intellectual life.

Just one other point, and this one a real criticism on college administration. The paper is quite correct in intimating that the demand and supply of engineers should be more closely correlated. As a first step toward providing that, the supply shall not too greatly exceed the demand,—I would suggest the more careful selection of student material. In most colleges there is little advice given the student as to the choice of a profession and still less actual restriction. As a result we have innumerable misfits, and the schools are setting for themselves impossible tasks, for not even a school faculty can make a silk purse out of unsuitable material.

As to the length of the course of study, it seems to me that there is room for both the four and the five year course. I am confident that in four years properly spent a satisfactory and creditable product can be turned out and, if provision is made for a fifth year for the student of special ability, I believe the demands of the engineering profession can be supplied.

There are many of the points in this able and comprehensive paper which are of particular interest to me. I will only say in conclusion that to me the consideration of the ideals it advances has been stimulating.

Mr. Morris Knowles:* (Member). Dr. Waddell's excellent and voluminous paper is so replete with thoughtful suggestions as to how to improve the status of the engineer that one is at loss to select out any one item of greater interest than another. The writer, however, has been attracted by the sentence upon page 473, under "Second," reading as follows:

> "Fundamentally, the interests of the profession are inseparably linked with those larger interests of the public which are paramount for the progress of mankind; consequently, it may be stated, without fear of contradiction, that the status of engineering can be improved mainly in one way, viz., by increasing its usefulness to humanity."

Also by the paragraph under the caption "Citizenship" on page 491:

> "Every young engineer should try to make himself a useful citizen and a credit to the community in which he dwells, as well as merely a successful practitioner. If all engineers were to do their full share of the work in local politics as well as taking part in the leading questions and problems of the times, our profession would soon be much more highly appreciated than it is, and, in consequence, the nation would be benefited; because, on account of their technical and business training, engineers, as a body, are capable of more effective effort than the men in most of the other walks of life."

Using these as a text, the writer is glad to call attention to the trite but yet needed declaration of the recognition of civic responsibility of the engineer. No type of citizen could be expected to assume a greater share of civic service. The engineer is, or should be, educated in the principles of the fundamental sciences

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and accustomed to the scientific method. He has been ta seek the truth at all costs and has learned the value of even when it is at variance with his interest or desire. He fore, has especial duties that other professional men do no

The engineer has been trained in logical thinking a acquired the habit of analytical study. He knows the dif between demonstration and verbiage and should be the las misled by fulsome phrases. He has had to shoulder the sibility of his own work, and has had less chance to doc blame for his mistakes than those of some other prof whose errors are more readily buried or explained away constant exercise of judgment has developed that rare qua an unusual degree.

But it is not only his mind and character that fit the en for civic leadership. His special training and experienc great additional value, because the problems of citizenship largely engineering in character, or are related so closely t neering questions. It is food supply, industrial developme transportation charges that today decide the issue of peace. National defense is a technical problem of organ and construction more than anything else. The labor probl grown out of the factory system, the invention of the engine, and the development of modern transportations.

Similarly, the problems of city life have grown out o neering progress and demand scientific remedies. The stea road, the trolley car, the telephone, paved streets, sewers, power, and the other products of applied science make *ci possible,* and it is the same means that must be invoked to *wholesome city life available.* Congestion of population is a problem in transportation; public health largely one of supply, sewerage, control of the environment, etc.

The engineer then is peculiarly fitted to assume civic r sibilities. He cannot, therefore, claim to have done his duty he does only as much as the average citizen. He is undes of the opportunities that are opened up to him unless he tak lead and recognizes a greater obligation in proportion greater capacity. Nor is his obligation fulfilled when he u special ability thoroughly to analyze and understand public tions and to cast his vote accordingly. He fulfills but half his obligation, and that the lesser half, unless he makes his influence felt in forming public opinion along proper lines.

Opportunities are not lacking to the engineer to fulfill his special duties as a citizen if he is willing to recognize the obligation. His special capacity for citizenship can be made of use to the community, provided he conscientiously directs his activities to this end. It is not enough that his works exert profound influence on the public welfare. These things help to *create* rather than *fulfill* the obligation. The engineer must meet his civic responsibility by training himself as a student for citizenship; by the development of all sides of his character after graduation, instead of confining his attention to professional advancement; by constantly keeping before him the public character of his work and its influence in the community; by taking active part in the actions of engineering organizations on public questions; by serving the public in official positions; by helping to educate public opinion through the press and the platform, if he has ability along these lines; by entering into the general civic and social life of his community; and by exerting an influence for better citizenship on those with whom he comes in contact.

We all owe a debt to Dr. Waddell that he has so completely catalogued the many ways in which an engineer can advance the profession and be of service to humanity.

MR. HUNTER McDONALD:* The logical manner in which the speaker has analyzed his subject has clearly demonstrated that some engineers at least can think clearly. His exhaustive treatment of the subject leaves little room for additions. The three divisions adopted are very aptly chosen and successfully handled.

In comparing the results achieved by different professions, the origin of each should not be overlooked. The legal and medical professions had their origin with the priesthood of the ancients. We have no record of the time when physicians and lawyers did not exist. Both professions deal principally with human beings and human affairs. Bad practice of the physician can be charged to the will of God, and it is sometimes fortunate for him that the final end of all of the subjects which he treats is dissolution.

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Bad practice of the lawyer can be attributed to the obstinacy of a jury, or the incompetence of a judge.

Engineering as a profession is less than 150 years old. In the past it has dealt almost altogether with facts and things. It is always subject to the one immutable law, that mistakes have definite consequences and can be definitely located and punished. Its successes have been so uniform that the public has grown to regard them as a matter of course, rather than a matter for congratulations or appropriate reward for the author.

The engineer's mistakes always result in loss of money or life, either of which is of serious consequence. Is it any wonder that his responsibilities often make him thoughtful, heavy and uninteresting?

Of late he has begun to realize that he also must deal and reckon with the human element. The awakening has come, but he must have time to stretch himself and rub his eyes, and determine his course. In due time he will accomplish this in the same efficient way that he does the more material things.

When he comes into his own, as come he must, his unselfishness and patriotism, which are a necessary part of every successful engineer, will enable him to accomplish more for the happiness of the human family in a century than the lawyers have done in 6000 years.

Until physicians became unselfish enough to study and practice preventive medicine, their accomplishments were little better than those of the lawyer.

The speaker's "first epoch" very properly deals with education. It is easier to purify the stream at the source than at any other point, and so the regeneration of the Engineer must begin at the preparatory school and college.

The writer agrees with the speaker in most of his recommendations for increasing the efficiency of students, and is in sympathy with the idea that an Engineer's collegiate education should be along broad lines of general information and habits of study rather than a stuffing of facts.

Modern languages are essential but he does not agree with him that Latin is a waste of time, nor does he think it necessary to acquire at college the art of speaking foreign languages fluently. With a basic knowledge, the art of speaking is readily acquired under compulsion of contact.

The broad general education is the foundation upon which to build the structure out of the materials gathered from experience. Specializing should be determined upon only after maturity of thought and development of tastes have made it possible.

The young engineer's possibilities for advancing the profession have been admirably stated by the speaker in his "second epoch," and the writer has no criticisms nor additions to offer.

In his treatment of the "third epoch" the speaker points out the shortcomings of the profession as expressed in the performance or lack of performance of Engineers associated into societies. The writer is ready to confess that all that he says and even more is true, but he does not believe that the remedy lies in the organization of new societies. The formation of the proposed American Academy of Engineers, would, in his judgment, tend to separate rather than unite the now already badly divided elements of the profession.

He believes that the proper remedy for the conditions, so ably pointed out by the speaker, is the bringing about of thorough cooperation among the societies already organized and not the organization of any others. He believes that an important step in this direction will be the acceptance by the American Society of Civil Engineers of the invitation of the United Engineering Society to occupy its building in New York jointly with the other National Societies.

He does not believe it feasible to establish a court for engineering ethics, unless its members are paid salaries and relieved from all other duties and anxieties, nor is it feasible for societies to undertake to name Engineers to fill important positions when requested to do so. This is a dangerous rock for the ship to encounter. It is far better to leave the selection to the client, and if need be let him make a few mistakes, than to engender the ill-feeling and bitterness which is a sure consequence of any attempt of a board of engineers to discriminate between members of the profession.

The establishment of a cooperative employment bureau for all engineers is much to be desired and entirely feasible. and a natural consequence of that co-operation among engineers which the writer believes is rapidly taking definite shape.

One of the first and most difficult steps to be accomplished is clearly to separate in the mind of the public the professional Engineer from the chauffeur of a locomotive and the hostler of a stationary engine. The adoption by field men of the khaki trousers and leather leggings, either in cities or in the woods, has tended to give the public the impression that all instrument men are engineers and all engineers are instrument men.

MR. MAURICE R. SCHARFF:* (Member). The writer desires to express his personal satisfaction in this thorough presentation of the status of the engineering profession and of the lines along which its improvement must be sought.

With most of what the author has said, he is in thorough accord, and he wishes especially to join in urging that engineers take an active part in the civic life of their communities, so as to perform the functions of leadership in the formation of public opinion and of official public service for which they are so well fitted by training and habits of thought. "From each according to his ability" is an essential principle of successful democracy, and we cannot expect the governmental experiment we are trying in the United States to succeed if so important a group of its best qualified citizens neglect their civic duties to concentrate solely on technical accomplishment.

With one suggestion of the author, however, the writer desires to express his disagreement. The truly cultured man must have something more, in addition to his technical equipment, than a "practical" working knowledge of English, modern languages, history, economics, etc. He cannot maintain his claim to culture unless he has achieved some appreciation of beauty in literature, in the arts and in music; some measure of idealism and an admiration for the finer qualities of human nature; a sense of the human relations involved by his place in the social and economic organization of which he is a part; and a recognition of the romantic quality of the engineering work on which he is engaged. Probably no system of education can accomplish these ends, unless the "material" to work upon is suitable. But most men—perhaps all, if we could only begin to train them early enough—have this capacity for the attainment of true culture. Without doubt the personality of teachers is the thing that counts most in the provision of the necessary inspiration and the development of this capacity. But, so far as educational methods can contribute, certainly nothing is so desirable as the intelligent reading and study of good literature, by no means excluding poetry and drama; the study of history as the development of social and political institutions, and for the inspiration of noble lives, rather than as a record of events and dates; and the study of economics in its social, as well as in its commercial and industrial aspects.

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*Principal Assistant Engineer with Morris Knowles, Consulting Engineer, Pittsburgh.

Such subjects may, and should be truly "cultural." But little can be accomplished along these lines if it is attempted to make the instruction therein wholly "practical."

MR. GREGORY M. DEXTER:* (Member). Shortly over a month ago there was an editorial in the *Engineering Record* commenting upon the loss to the profession through the death of Mr. C. C. Schneider. It was stated that he took an unusual interest in the welfare of his associates, that he was anxious for the success of young men, and that he would go out of his way to assist in their advancement. The editorial was a strong recognition of the value of that fine note of brotherhood which is spreading among us. Its recognition of those lovable qualities in Mr. Schneider which constitute nobility of character was an inspiration.

There is a need for more of such engineers. There are too many engineers who are dissatisfied with the lack of cooperation in the engineering profession. It was with decided pleasure, therefore, that the writer listened to the suggestions for improvement advanced by Dr. Waddell. His remarks are another indication of the growing recognition of that broader viewpoint so necessary if as a profession we are to stand high in the estimation of the public.

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*Junior Engineer, U. S. Engineers, Wheeling, West Virginia.

To Dr. Waddell's suggestions, the writer would add, or emphasize, as follows:

Those of the engineering profession who hold high executive positions should give public recognition to the work of their engineering associates. The timetable recently issued by the Delaware, Lackawanna & Western R. R. is an example of what might be done.

Our societies should emphasize those qualities of sympathy, integrity and nobility in an engineer entirely apart from any recognition of technical ability. Arrangements should be made for the award of honors to engineers who possess in marked degree those finer qualities which constitute the thorough gentleman. Such honors would be consistent with insistence upon adherence to a high code of ethics. Those guilty of dishonesty or sharp practice should be expelled from membership in our engineering societies. Some attempt should be made to curb those engineers who are not considerate of the rights of their associates or subordinates.

The attempts which are being made to bring about a greater popular appreciation of the value of the engineer are worthy of the heartiest support. In connection with these attempts, the establishment of the Alvord Medal in the Western Society of Engineers in recognition of public service should be noted and commended. In these attempts at least one society has endeavored to assist by means of snappy newspaper articles. This idea might well be extended to the employment of a lecturer, by a group of our engineering organizations, who would emphasize to the public the poetry behind all engineering work. From this it would be but a step to a modest advertising campaign in a carefully selected list of periodicals. Such advertisements would embody much of the spirit in those of the American Telephone & Telegraph Co. The employment of a lecturer or the use of advertisements in awakening popular appreciation for the engineer would require money and a strong brotherhood in the profession. It is not chimerical, however, if we adopt the slogan "Every engineer the member of at least one society."

A direct interest should be taken in the conditions surrounding the employment of all engineers. The maintenance of a national employment bureau by a combination of all engineering societies is a necessity. In connection with such a bureau, each society should have its local agency. Attention should be directed to the reduction of peaks in the employment of engineers. The wastefulness of a policy of hire one day and fire the next is frequently apparent. Many of our industries recognize this and, as in the manufacture of automobiles, are endeavoring to maintain approximately uniform speed of production. An increasing number of engineers are being employed on public works. For these men civil service rules should be protected and forceful representations should be made against political methods of appointment or removal.

A few weeks ago, seventeen, efficient, capable engineers who had been in the employ of the city of Boston for seven to forty-one years were summarily discharged on forty-eight hours' notice. It remained for seven representative engineers in their private capacities to protest to the Mayor of Boston against the removal of such men without just cause and contrary to the spirit and intent of the state civil service law. To the best of the writer's knowledge and belief, no official notice has been taken by any engineering society of the City of Boston's violation of the civil service regulations. That such is the case is a sad commentary. On the other hand all honor is due to Messrs. Frederic Stearns, Desmond Fitzgerald, Harrison Eddy, Frank Barbour and others for their prompt protest.

The writer is by no means in accord with a movement for a union of engineers in the sense of the word as used by "labor." Nevertheless, the discussion now raging among the members of the dramatic profession as to the relation between art and union cards has a sidelight of interest for the engineering profession. Accordingly, the following is quoted from an article in the *New York Times* for March 12, 1916. It is taken from an account of the remarks of one speaker at a meeting attended by 800 actors and actresses.

> "The pride of art is really a wonderful thing—wonderful as long as you keep it in activity. But the moment you allow it to break out and run wild it becomes a serious menace to the dinner table. Duval, the French artist, died of starvation. Shortly before he died he painted a picture, which, after his death was hung in the Louvre—and he was a great artist, but he was a dead one. See how much more wonderful and more comfortable it would be if we could solve the problem of being artists and human beings at one and the same time. By human beings I mean men with ordinary common sense. You know a man, an actor, does not sacrifice his artistic dignity if he happens to be a man of ordinary common sense or a business man."

There is no doubt that in many cases actors have been ruthlessly exploited by managers and theatrical agencies. Also, there is no doubt that somewhat similar abuses exist in the relations between employers, public or private, and engineers.

Dr. Waddell's paper will not serve the purpose for which it is so eminently fitted, however, unless it results in concrete action. For this, we need not wait upon any one engineering society as there is a large field in our own work for much of what has been suggested. Neither is it necessary that we be chief engineers of this or that company. As squad leaders, assistant engineers, chief draftsmen and whether we have charge of two or fifty men, we may show interest in the work of our subordinates. Patience in explaining away a difficulty is in line with the spirit of Dr. Waddell's paper. It is well to remember that what is easy for us today was probably at one time difficult. A letter of introduction, the loan of a book, or advice as to studying are other methods of showing interest. It is not difficult to go a step further and set aside an evening now and then for the entertainment of groups of the men working under us. Such action will develop a sympathetic understanding of the problems affecting the rank and file of the engineering profession. Once that understanding is generally diffused, we may expect that strength of co-operation, that betterment of conditions in the engineering profession for which Dr. Waddell has pleaded so ably. Such a scheme is not elaborate. It is true that it does not offer glory as chairman of this or that committee. It merely requires nobility of character. Those who follow it will recognize that their success is a queer combination of hard work, skill and opportunity. Such a result may wound our vanity, but at least it will be an augury of better conditions for many of our engineering brothers.

MR. GARDNER S. WILLIAMS:* Dr. Waddell's address upon the "Advancement of the Engineering Profession" has been read with interest.

Referring to his suggestions upon the education of the Engineer, the writer heartily endorses the first six. As to the seventh and eighth, making the study of Spanish obligatory, and providing a speaking knowledge of foreign languages, he is very much in doubt. The value of a foreign language lies not alone in the ability to speak it, which latter is ordinarily of purely commercial use. The literatures of France and Germany are a thousand times more valuable to the Engineer than is that of Spain, and should be within the grasp of every consulting or designing engineer. For the field man or superintendent of construction they may be of less or perhaps little consequence, and so is Spanish, unless he be brought into contact with Spanish speaking peoples. It therefore seems that the acquisition of a reading knowledge of French and German is of more value to the Engineer than is a speaking knowledge of either or of Spanish alone. While it is quite true that much business will be done with South and Central American countries, after all is said and done, only a comparatively few Engineers will go there to do it. To the writer's mind the greatest value of the study of a foreign language is in the training it gives in the use of one's own. In no other way can the proper and distinctive use of English words be so well taught as in the translation of a foreign tongue, and in this particular the Latin language excels all others that have come within the writer's experience.

With the remaining four suggestions the writer is in accord, but he considers more important than any of the twelve, the training of the student to be a man and a citizen before he is an Engineer. Honor and the ability to use the faculties with which nature has endowed him are the prime essentials to a successful career in every line of endeavor and should never be lost sight of in any scheme of education, and while the Author's program provides for the latter, the first, without which no man is qualified to be an Engineer, appears to be overlooked.

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*Consulting Engineer, Ann Arbor, Mich.

The proposal of an Academy of Engineers as presented by the Author has much to commend it, and if it can be started with a group of men who will really measure up to the best there are in the profession, it can be made a success, but if those first selected are not such as all can look up to, it will be difficult for it to wield the influence desired.

The writer agrees with the preference for a Federal License for Engineers, rather than a State License, but is still uncertain as to whether either is really desirable.

PROF. CHARLES F. SCOTT:* (Member). Dr. Waddell's perspective view of the engineering profession presents many points for the serious consideration of engineers, teachers and students. I suggest that it be put in available pamphlet form for wide distribution.

In the serially numbered items relating to the profession in general, there are three or four which deal with the meagre recognition which the engineer and his profession receive at the hands of the general public. The implication is that the public is at fault. Practically every other item in the long list deals with the short comings and the inadequacy of the engineer, both as an individual and his relation to his profession. If the engineer is inadequate as is thus indicated, is it the public or the engineer himself who is at fault because the desired recognition of the profession is not forthcoming?

A point which has not been emphasized is the newness of the profession. Present engineering schools, the national engineering societies, many important branches of engineering, the development of public utilities in which engineering comes into close relationship to the public, the development of many kinds of industries which are dependent on engineering, are largely the product of a single generation. It is no wonder that engineering itself and engineering in its relation to the modern civilization which it has produced are not fully established and definitely worked out. We are in a period of growth and transition and evolution. Engineering forces, long working beneath the surface, are now coming into prominence. We must recognize what has been done and not be too critical of what has not yet been accomplished. The present paper and its discussion should aid in the constructive formation of a better future.

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*Professor of Electrical Engineering, Yale University, New Haven, Conn.

PROF. WILLIAM E. MOTT:* (Member). Few topics offer more opportunities for discussion than the education and training of engineers, and Dr. Waddell's paper brings up many points upon which widely different opinions are held. The writer is disposed to question a number of the points enumerated under the "First Epoch." As the teacher feels that many of our educational difficulties would disappear could we direct the training and preliminary schooling of our prospective students, so the engineer is convinced that under his specifications the college student would be properly prepared for the practice of his profession.

If four years of college are too few for certain students to acquire a proper amount of training, there are, I am confident, just as many cases where the four years have proved a detriment and each additional year of study for such young men means a lessening of their capacity to do effective work in the business world. As our technical institutions are now conducted, four years of study are quite enough for a great percentage of the students therein, and any extension of this period of what, at best, resembles a forcing-house growth, is apt to result in too much leaf and flower and not sufficient strength of stem and depth of root.

There are quite enough colleges, universities and technical schools today offering ample opportunity for graduate study without the "establishment of separate schools for post-graduate engineering work of all kinds."

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*Professor of Civil Engineering, Carnegie Institute of Technology, Pittsburgh.

One fundamental difficulty in many engineering schools is the feeling on the part of parents, and many administrative officers as well, that an indifferent student once admitted to the freshman class, should be given repeated opportunities to maintain standing.

It is one thing to argue that the business world will give the boy but one chance to make good and that the same rule should apply to the student; it is quite another fairly to meet the very human and often touching problems that appear when an indifferent student is threatened with being dropped for low standing in his classes.

The grade, or high school, student suffers from too much rule-of-thumb teaching and is rarely put upon his own responsibility. The college freshman begins his course with the same viewpoint as he maintained at school and the first duty of the technical school instructor is to disillusion the boy and to teach him a sense of responsibility.

The young man with some experience, one upon whom responsibility has already rested, is rarely a subject for faculty consideration during his college career, and upon graduation he fits into the engineering world without jolt or jar. Many institutions coddle the student during the entire four years of his work, setting him again and again upon his course after repeated groundings; others provide pilots who are always at hand to advise and steer the student when he runs too near the shoals; and still others simply furnish the boy with chart and compass and leave him to steer his own course.

Each of these methods may be adapted to certain students but some sure method is indispensable whereby the average boy shall, early in his college career, be brought to realize his individual responsibility for his own progress and the privilege of remaining in the institution. Comparatively few students realize these points, and until this end is accomplished, efforts to arouse enthusiasm for the profession, to inculcate love of study and work, etc., will prove fruitless.

Doubtless some of our engineering graduates will need a working knowledge of Spanish, but it will be many years before a large percentage of them will need to read and speak the language. It is desirable to put Spanish on the same basis as French and German in our curricula, but to require a good working knowledge of all students seems unnecessary as yet.

The writer would touch upon one more question even at the risk of being thought sensitive upon a point of professional standing. We all acknowledge the importance of proper educational guidance for our sons and daughters and until the teaching ranks are filled with the right kind of men and women, our schools, from the lowest to the highest, will not properly perform their functions. Every possible inducement should therefore be extended to the young man who shows a disposition to enter the teaching profession, provided he is mentally and temperamentally qualified to be a teacher.

The teacher has to work today under a heavy financial handicap and he realizes this from the start. Ought the prospective instructor to be told further that the responsibility involved in training future engineers is only half as great as if he were "bossing" a gang of men engaged in railroad, or other construction work?

Under the heading "American Academy of Engineers," "responsible charge" in teaching work must extend over twice as many years as if the work is design or construction.

It would be quite logical and perhaps eminently proper to exclude teachers of engineering from membership in an Academy of Engineers, but if they are to be eligible it would seem only fair to acknowledge that the work of directing the development of our future engineers is quite as serious business as many lines of engineering activity which are now technically regarded as "responsible charge."

PROF. WILLIAM H. BURR:* The evidences of disturbed feeling regarding the status of the members of the engineering profession in the community at large are too abundant to be ignored and Dr. Waddell's paper constitutes a forceful instance or expression of that feeling. Similar expressions and scarcely less forceful have been put on record to the same end by a number of prominent members of the profession during the past year or two, or possibly during the past half dozen years. It is therefore fair to presume that there is substantial foundation for a grievance. Remedies have been suggested of no less variety than number and yet little progress seems to be made toward a cure of the disturbing situation.

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*Professor of Civil Engineering, Columbia University, New York.

Some have suggested that resort be made to a code of ethics, assuming that all members of the profession would respect such a code. Some have declared with more or less reason that the members of the engineering profession should acquire the faculty of using good English and those graces of speech and personality which make one's society agreeable and attractive to those about him; others again, like Dr. Waddell, would not only endorse such procedures, but add more education including instruction in English throughout every year of the professional school and at the very outset of the latter impress upon the beginner the grand attributes of the profession so as to stimulate him with enthusiasm for his calling; and so on to the end of the list.

Dr. Waddell quotes with approval a number of excellent points made by Professor George F. Swain in an address made last year before the Institute of Electrical Engineers to the effect that the engineer has not the same breadth and clearness as his professional brother, the lawyer, in his mental activities. And furthermore, that the mathematical training of the engineer narrows and hampers the latter, so that his professional mentality, so to speak, is defective, as compared with the man with legal training. After quoting some instances of disparagement, Dr. Waddell gives a list of fifteen alleged undesirable conditions and "defects in the general make-up of American engineers." It will be difficult at least for some engineers to realize fully what a number of these alleged defective characteristics of individuals can have to do with the status of the engineering profession as a whole. The most of these allegations might be urged against many members of any profession as they relate to personal idiosyncrasies rather than to prevailing features of professional life.

Further on the author asks "What are the interests of the profession? And what is the limit of their advancement?" It is not clear whether reference is made in the second question to the interests or the principles of the profession. However, that may be he states "that the engineering profession is especially interested in securing, first, proper recognition, second, adequate compensation, third, increase of professional knowledge, fourth, proper balance or adjustment of various classes and numbers of engineers to meet the needs of a developing country." After some discussion of these matters, Dr. Waddell comes to the conclusion that the courses of study in engineering schools require, in order to give the engineer requisite increase of professional knowledge, substantial betterments in twelve different directions, and it is probably true that even more abundant betterments are needed.

The whole paper is characterized by views of many defects made clear by the author's long professional practice and experience in educational work during a number of his earlier years of professional activity. All of these features of this forceful paper are excellent and undoubtedly the engineering profession would be much better off if the suggested improvements could be enforced upon it, but the same observation can be made with practically equal force and pertinence to the legal and medical professions or to any other profession. They are simply the expressions of fundamental principles which ought to characterize educational and other training for any professional field whatever and it is probable that the legal and medical profession need their application just as much as the engineering profession.

It may be admitted without violating the truth that the engineering profession and its members merit every word of criticism found in Dr. Waddell's paper and even more, but the defects of public recognition, lack of proper standing in the community, lack of demand for engineers to fill administrative and other broad positions, failure to produce finished men and gentlemen in the best sense of the word and all the other lacks and deficiencies enumerated would not necessarily be cured if every corrective measure advocated by him could be effectively applied, although undoubtedly many individual members would be wonderfully improved in various ways thereby.

The true cure for the professional deficiencies which lie at the foundation of the complaints or disturbed expressions which have been uttered not only by the author of the paper under discussion but by many others involves a treatment of some characteristics of professional procedure among engineers and the consideration of some personal features of the matter which certainly would be unwelcome to many members of the profession.

It is unfortunately an individual matter, not to say personal. Lack of breadth of educational training is undoubtedly responsible for many professional evils not to say evils of individuality or personality.

At the present time the engineering profession possesses practically nothing to indicate that it is a profession except the educational training given to its beginners in the engineering school and that, as Dr. Waddell states, is in some respects seriously defective, but both the legal and the medical professions had their standing recognized and awarded by the community as a whole when the educational training of the members was even more narrow than the general educational work done in or prior to the engineering schools at the present time Any land-surveyor, locomotive-driver, or chauffeur even, may call himself an engineer and the public as a whole will award him what he claims, while true members of the profession either do nothing or mildly criticise the procedure. There appears to be insufficient professional spirit to assert a proper dignity and secure such discriminatory legislation, as shall convey to the title its honest meaning and defend its use. Various attempts have been made to secure legislation which through a proper procedure of licensing would give to engineering the professional standing due to it, but the members of the profession have not yet attained to a sufficiently broad and intelligent view of the matter to extend their vision beyond certain personal considerations and demand such measures as may protect and dignify the profession as a whole. The public is generally ready to accept at their own valuation any body of intelligent and honorable men, but if a body of even such men lack sufficient self-respect to assume and occupy worthily a professional plane and conduct their work in a suitable and professional manner, the public may hold them even cheap and certainly will fail to accord the recognition properly desired and claimed by Dr. Waddell, Professor Swain, and other prominent and true members of the profession.

Again, it might as well be frankly stated in such a discussion as the present that every experienced engineer knows there are many cases of procedure of members of the profession of such character as to fall far below the requirements of any worthy code of ethics, even if such existed. It is true that there is a so-called code of ethics enacted by the Board of Direction of the American Society of Civil Engineers but the less said of it, the better. Not that there is anything inherently wrong in it. In fact it may be designated as a distinctly "goody, goody" Sunday school set of rules, which certainly ought not to be violated. They are commonplaces of elementary virtue with all the merits of such primary guides to goodness, but as out of place for a great professional body of men as would be innocent childish antics or boyish behavior in the discharge of professional duties. A proper code of ethics ought to be couched in dignified and worthy expression and so composed as to set forth in suitable fullness general rules of professional procedure so as to give moral character and ethical features to professional practice. At the same time there should also be set forth such principles of professional procedure as would give to the public a clear and simple statement of the duties to be performed by engineers, so as to secure uniformity, thoroughness and justice in their dealings with clients. Fortunately the code in question as enacted was so short, insignificant and inconsequential, as probably never to have been seen by more than a few, if any, outside of the professional organization in which it originated.

A true and proper code of ethics is badly needed. It should be formulated and made known to the public at large in which engineers are to practice their profession. Such a measure properly perfected and set forth would go far toward securing proper recognition of the profession and the rates of compensation to which its members are entitled. In the absence of such a code, however, there will be irregularities, underbidding, jealousies, all too often with attendant evils of smallness and meanness utterly inconsistent and abhorrent to true professional spirit.

The defects against which engineers contend are not those which can be cured by any improvement of education, nor by patting each other on the back and congratulating ourselves that we are members of the grandest of all professions and that there can be no human progress except that which as engineers we create, all of which is little more than pure froth. When engineers, like other professional men, become finished practitioners, guided by high moral principles and earnest desire and determination to perform their duties in a thoroughly professional manner, it will not be necessary to resort to any adventitious means to secure public recognition or to agitate formal devices for the purpose of securing increased compensation. The best and most effective members of the profession secure satisfactory recognition and compensation at the present time, but unfortunately they constitute much too small a minority of professional workers in engineering.

DR. GEORGE F. SWAIN:* Dr. Waddell has done me the honor to refer to my address before the American Institute of Electrical Engineers, and I wish I might find the time to discuss in some detail his admirable paper. This, however, I cannot do, but I will make a few brief remarks.

Dr. Waddell has unintentionally given a slight misconception with reference to my statements. I have nowhere expressed the opinion "that the *leaders* in engineering are in any way inferior to the *leaders* in other learned professions in clarity of thought, straight thinking, or breadth of view." This might be inferred from Dr. Waddell's statement, although he probably did not intend it. On the contrary, I believe that the *leaders* in engineering are quite the equals, in the qualities referred to, to the leaders in any other profession. I do believe, however, that the training and experience of the engineer is *on the whole* not as broadening and not as conducive to the development of qualities which make leaders as the training in law and in business.

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*Professor of Civil Engineering, Harvard University, Cambridge, Mass. Past President, American Society of Civil Engineers.

Dr. Waddell has referred to statements of Professor Gray, of the University of Minnesota, an economist. Professor Gray is well known to hold the belief that engineers are in no way fitted to discuss general economic questions. Engineers, however, will probably not be disturbed by such criticisms. In the opinion of the writer, the greatest harm that is being done in this country today, not only to the cause of straight thinking and justice but to that of education, is a result of the prominence given to the study of economics and sociology, and to the activities and dogmatism of a certain class of economists, with no experience in business, who yet presume to think that having studied each other's books they are qualified thereby to lay down the methods in which the business of the country should be conducted and the economic problems solved. Economics and sociology are indeed not sciences in the same sense that the physical sciences are. Experiments cannot be made in a way to lead to conclusive results, because more than one element cannot be varied at a time. The field is wide open for the exercise of prejudice, temperament and sentimentality, and a great many of the propositions put forward are based upon these things rather than upon logical deduction. A most discouraging thing is to see so many students in our universities specializing in these subjects. When a young man without experience in business or in life, and without having been trained in the true sciences, so that he knows what is proof and what is not, finds the professor of economics or sociology in one college holding diametrically opposite opinions from the professor in another college, it is very natural that he should come to think that one opinion is as good as another. If he is self-assertive and intellectually arrogant, he will very likely come to think that his own opinion is as good as anybody's else. If he is inclined to be intellectually subservient he will very likely accept and voice the opinions of the teacher who most forcefully impresses him. It is almost self-evident that the engineer, if properly trained in science and mathematics, and if broad enough to interest himself in economic and sociological questions, although these are outside the technical details of his profession, will be a safer guide on these matters, and possessed of a much more judicial attitude of mind than economists of the type referred to. Fortunately there are some economists who do not belong to this type.

In order that the above may be true, however, the qualifications named are necessary. The fact that an engineer constructs a work which stands does not prove clarity of thought, nor is this quality demonstrated in the case of a lawyer by the winning of a lawsuit.

The writer believes that to advance the engineering profession the following things are necessary:

(1) To Improve Engineering Education: This should be in the direction of broadening and simplifying it. Our engineering schools should not attempt in a four-year course to carry the student as far as they do, but should give more drill on fundamentals, and should include in the curriculum a brief course in economics or business, the principal object of which should be to give the student an idea of the scope of those subjects and to interest him in them, so that he will pursue them later either in post-graduate work or by himself. The writer does not believe that the ordinary engineering course should be longer than four years, but he believes it essential that post-graduate courses should be offered in *a few* institutions sufficient to take care of all the students, from *all* the institutions, who are qualified for advanced technical education.

(2) To Encourage the Best of Our Young Men to Enter Into the Profession of Engineering: This may be done by brief courses of lectures in our colleges and in our elementary schools, treating of the various professions. The average college graduate knows little accurately of the opportunities which are possible in the various professions, and his choice of a vocation is largely a matter of chance. If young men could be made to realize the scope of the engineering profession, the durable satisfaction which it offers, its contributions to civilization and material welfare, a larger proportion of able young men would enter the profession than is now the case.

(3) The Compensation of Engineers Should Be Larger: Many an engineer now receives less compensation than a carpenter, although his work is much more valuable. This may be accomplished if engineers will learn how to value their services, to charge for them adequately, and to insist that the pay of their subordinates be made proportional to the real value of their work.

(4) By Co-Operation Between Engineers of All Kinds: This may be done largely through the engineering societies. The recent vote of the American Society of Civil Engineers to move to the Engineering Building, on Thirty-ninth street, is a most promising indication. The more intimate the co-operation between the societies and the individuals of the societies, the more engineers in the different branches will unite and exert themselves in public affairs, the greater will be the influence which the profession will exert, and the consequent recognition which it will obtain.

(5) By the Recognition of the Personal Eminence and Services of Distinguished Engineers: The proposed memorial to Alfred Noble is a most important indication that this can be done. An engineer who conquers the air or who overcomes a great physical obstacle in promoting one of the great agencies of human welfare, such for instance as the telephone, is by right entitled to greater recognition than a soldier who wins in a battle.

(6) By the Recognition in Our Government of the Place Which the Engineer Holds in Modern Life: In the opinion of the writer, there should be a Secretary of Public Works in the Cabinet of the President, and all public government work of an engineering character now scattered through various departments should be co-ordinated under this Secretary, who should be an engineer and a good man of affairs.

It must not be forgotten, however, that sentiment will still work against the engineering profession, for the work of the engineer appeals to neither hope, fear, avarice, nor vanity. The progress of the profession may, therefore, be slow, but if we all pull together we may perhaps do something to hasten it. More than all, the engineer should interest himself in public affairs, and serve the public even at some self-sacrifice, if called upon to do so. This is a lesson that the engineering profession has not yet learned.

Dr. J. A. L. Waddell:* The appreciative manner in which this address has been received by the members of the Engineers' Society of Western Pennsylvania is a matter of deep gratification to its author; and he herewith tenders his hearty thanks therefor to the Society as a body and to the various gentlemen who have done him the honor to discuss the points which he has raised.

The author agrees with Dean Bishop in his claim that "In the matter of research Pittsburgh should stand preeminent," for it certainly is the center of engineering industries in this country. The establishment of a great laboratory there, controlled by men of wide experience, would be of inestimable advantage to the entire enginering profession.

The joint research committee mentioned by Dean Bishop as being established by the Society for the Promotion of Engineering Education is a move in the right direction; but, in order to be truly effective, it will require financial aid which that society is unable to furnish. The influence of its members, however, ought to result in securing the funds necessary for operation.

Concerning the proper duration for engineering courses, about which Dean Bishop disagrees diametrically with the author, the latter desires to state that he is firmly of the opinion that the time has come to make a fundamental change. He believes that one of these two schemes will have to be followed: Either all first-class engineering courses will have to be extended from four years' to five years' duration, with eleven working months to the year for the students; or else the lower-grade students will have to attend trade schools, the present purely technical four-year courses will have to be curtailed by omitting most of their so-called practical features in order to allow time for more theory, better drill in the fundamentals, and a large increase in cultural studies, and the really fine students who have the ambition to advance beyond the rank and file of their fellows will have to go for one, two, or even three years to post-graduate schools of engineering, where they can be taught all that is generally known to the profession in its various branches. As young Americans are eager to get into harness as quickly as possible and cannot, except in a few cases, be persuaded to devote more than four years to the obtaining of a technical education, it is probable that the second scheme will have to be followed. Should we jog along as we have been doing and give only four-year engineering courses, we shall assuredly drop behind the technical men of Europe—which would be a national calamity.

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*Author's closure.

Dean Bishop's surmise that the book of "Addresses to Engineering Students" was intended to be used occasionally but not continuously, is correct; because a single one of the fifty addresses that it contains is generally sufficient for one sitting. By the way, it may be of interest to know that portions of that book were translated into French for a government publication by a young engineer named Andre Rabut, the son of an eminent French railroad engineer. The young man fell in battle five days after reaching the front, but his family has since attended to the issuing of the book, which is intended for use in the technical schools of France.

What Mr. John A. Ferguson says about the necessity for an engineer to be a good business man in order to attain eminence in the profession is truly sound, as is also his statement of what is expected of any engineer who attains eminence.

The scheme of setting practical problems for solution by engineering students mentioned by Mr. F. N. Speller is admirable; and its general adoption would be conducive of much good. The author has lately acted as one of three judges in a similar competition by certain students in the University of Illinois; and he is now contemplating an attempt personally to inaugurate competitions in a number of the leading technical schools by offering an annual prize to each for the best solution of a set of problems in the hydraulic study of a proposed crossing of a river and the subsequent economic layout of a railway bridge.

In respect to Mr. Samuel E. Duff's remarks concerning the proposed American Academy of Engineers, the author would state that it is the intention to choose the members from the engineers who are most prominent in all branches of engineering—civil, mechanical, mining, electrical, chemical, metallurgical, military, naval, etc. The only reason for requiring membership in one of the national societies is the general idea that every engineer ought to belong to at least one of them, no matter how many other technical societies he may join.

The author agrees with Mr. Duff concerning the advisability of the establishment throughout the country of local engineering societies of the high character and standing of the Engineers' Society of Western Pennsylvania, the Boston Society of Engineers, and the Western Society of Engineers; but even if all of such local societies were to cooperate, they would not be able to attain all the objects of the proposed American Academy of Engineers. Various societies having identical objects but located in different parts of the country would not find their interests conflicting; but, on the contrary, they would aid each other materially, and they would be a help instead of a hindrance to the national engineering societies. At the head of all would be the Academy composed of a limited number of the older members of all the other societies—men who have made good, who have no personal axe to grind, and who are more interested in the development of the engineering profession than they are in their own individual careers.

Mr. Duff is correct when he remarks that today the "great State Universities and the great Western Universities that are not under state control, are graduating engineers just as well trained in the fundamentals of their profession as they ever were in the east." This is a statement that the author has been making during the last decade and one which he has had to defend in controversy on numerous occasions. In fact, he has gone a little farther by stating that there is a greater amount of energy and snap among both students and professors in the engineering departments of the universities of the middle west and of the Pacific coast than there is among those in the eastern technical schools and universities. Especially is this true of the students, because most of those in the west go to college for the sole purpose of obtaining an education, while many of those in the east go so as to have a good time, or so as to comply with the wishes of their parents. It often requires the pressure of poverty to make a student work hard—and most of the western students are poor—but the best results in technical education are obtained when a student is provided with a moderate amount of money. Too much will tend to distract him from his work, while too little will necessitate his having to spend in the earning of money much time that otherwise might be advantageously employed in study or in mixing on terms of equality with his fellow students. College life outside of the class room constitutes an important part of students' education; and those of them who have to grub for a living can seldom participate in it, hence they lose most of its advantages.

Mr. Duff stated in his oral discussion that "Dr. Waddell's suggestion of a six-year course should be modified to some extent so that practical work is taken up sometime during that course." The author goes further than that, for he advocates a certain amount of practical work in each scholastic year and the giving of as much thereof as possible in the freshman and sophomore years, even if, in order to do so, it be found necessary to divide a number of courses, such as physics, chemistry, railroading, or bridges, into two parts, elementary and advanced, thus giving the students some practical notions concerning the engineering profession before studying sufficient mathematics to enable them to comprehend the advanced work. Unless this be done, many students who are eager to begin their life work will become discouraged by the study of theory alone and by failure to see any practical application of what they are learning. Many such discouraged students quit the course and take up some occupation other than engineering.

Mr. Edward Godfrey is right in claiming that all experiments on reinforced concrete should be unbiased and made as free as possible from commercial interests. The profession will not put much faith in the results of experiments made directly by business concerns or their regularly employed engineers; but they will credit the statements of independent investigators or specialists of established reputation, notwithstanding the fact that they are paid to do the work of experimentation.

He is also right when he sounds a note of warning against the building of dangerous structures in reinforced concrete; for there are today many irresponsibles in this country who are designing weak concrete bridges, and who are trying to foist upon the public freak designs for the sole purpose of cutting down first cost and thus disposing of their wares. Within the last few weeks, in the case of a proposed large and important structure, two such freak designs were submitted and seriously considered for acceptance; and had it not been for the firm stand taken by the author and some hard missionary work that he did, one of them assuredly would have been adopted. The result would almost certainly have been a great disaster to life and property, unless the failure occurred immediately upon the removal of the falsework. The only method of excluding such freak and faulty designs from materialization is the employment of bridge experts of established reputation, preferably to prepare the plans, or, otherwise, to pass on those submitted in competition.

Mr. Rayman's suggestion of improving the status of the engineering profession by forcing better compensation is of prime importance; and all engineers should join earnestly in an endeavor to attain that end instead of aiding employers to keep the salaries of subordinates down to the lowest practicable figures. Engineers in all lines and grades are inadequately paid for their services, and the sooner this crying evil is corrected the better will it be, not only for the profession, but also for the nation, in that with greater compensation established, better men would be attracted to our ranks, and more satisfactory work would result.

The author desires heartily to thank Mr. A. Stucki for his kind and appreciative words concerning the address.

Answering the discussion of Dean Leete, the author would state that while it would be greatly desirable to have the students taught many things at their homes instead of in college, in numerous cases it is impracticable to do so, because the boys often come from families that are uncultured and among which correct English is unknown. Again, many of the boys' parents are foreigners, some of whom do not even speak English. Such students need the help of their instructors to teach them proper diction and how to carry themselves when they enter the business world. Sometimes they learn these things from their college associates; but in many institutions the mass of the students is lacking in culture, and hence, under such circumstances, one's mixing with his fellows would accomplish but little in respect to these requisites.

As for "the inculcation of a love of study and work for their own sake and not mainly because of the money that can be earned thereby," the young man very seldom obtains this at home, even if he belongs to a well-to-do family; consequently, this task is certainly the duty of the professors, and especially of the dean. That the undertaking is a difficult one goes without saying, but what are engineers for except to overcome difficulties? The greater the difficulty the greater the satisfaction experienced in overcoming it; and if the faculty of a technical school succeed in turning out cultured, ambitious, and energetic graduates, what greater satisfaction could it experience?

Dean Leete has struck the keynote when he says it is necessary to change the attitude on the part of the student and make him "realize that English and cultural studies and general scholarship are as vital to him as mechanics and laboratory practice." If this can be done at the very outset of his scholastic career, it will change his entire life, both at college and throughout his professional work, making him a better and more useful man for the community and a much happier and more successful individual. The importance of accomplishing this at the very start cannot be exaggerated. It should be the first duty of the dean at the opening of the scholastic year; and he should urge his teaching staff to aid him in the endeavor in every feasible way. Lectures on the subject by practicing engineers who have been successful will do much towards making a permanent impression upon the receptive mind of the embryo engineer; and they should be arranged for to as great an extent as possible. This feature of lectures from outside sources is one of extreme importance in any technical curriculum; and it is the author's belief that the practicing engineers will be found ready and willing to give liberally of their time and energies in order to aid the teachers of engineering in their important and difficult task of properly training the men who are to do the engineering work of the succeeding generation.

As for the proper inducement to hold out to students to get them to take interest in the study of English and cultural subjects, of course, it would be better to have them work for the "broadening and enriching of their intellectual life," and they certainly should be approached on this line; but the "bread-and-butter standpoint," unfortunately, will appeal to many of them far more strongly, hence it should not be overlooked. The end to be attained in dealing with them is the important thing—the means is a subsidiary matter.

Dean Leete is right when he suggests the "more careful selection of student material" in order to adjust the supply of engineers to the demand. In following this course another important purpose would be served simultaneously, viz., an improvement in the quality of the graduates and, therefore, of the profession. Too many institutions are striving to turn out large numbers of alumni, but in so doing they make a serious mistake; for quality not quantity is the true *desideratum.*

To all that Mr. Morris Knowles says concerning citizenship and the peculiar fitness of engineers for civic responsibility, the author most heartily subscribes. Unfortunately, in the past, engineers have rather neglected their civic duties. For this there are two prime reasons; first, they have been so busy with their individual professional work and have taken such a deep interest in it that they have been unwilling to spare the necessary time; and second, being, as a class, men of high ideals and by training more than usually honest, they have been averse to mixing in party and ward politics, both of which, it must be confessed, are generally far from being of a character to attract men of integrity. The first reason is not valid, because every man owes a debt to the community in which he lives; nor is the second one much more so, for the reason that the entrance of engineers into all divisions of politics would have a tendency to purify them, thus effecting many needed improvements in the national, state, and municipal governments. At first the engineer who mixes with ward politicians is likely to feel that he is, in a certain sense, degraded by their contact; but after his influence begins to become felt, it will act as a leaven to the rest, and will prove to be the means of stamping out dishonest practices and of rendering the work performed much more effective than formerly.

The author desires specially to thank Mr. Hunter McDonald for his comment and criticism, based as they are upon a breadth of professional experience that is not often equalled. His few points of disagreement from the author's views are mainly debatable ones relating to methods of accomplishment rather than to results desired.

Answering Mr. Maurice R. Scharff's point of disagreement with the author's claim that the cultured engineer should have a "practical working knowledge of English, modern languages, history, economics, etc.," the author concedes that a certain amount of study of "beauty in literature, arts, and music," would be beneficial; because the development in any individual of literary taste and capacity to criticise correctly paintings and musical productions certainly would make him more influential and appreciated in the community, besides affording him great personal satisfaction; nevertheless, it is submitted that the study of purely cultural subjects by students of engineering could readily be carried to an extreme, and that time spent on musical training in most cases would be almost entirely wasted, because of the prevailing lack of natural ability to appreciate music. Again, according to the author's experience in college life, the prominent members of glee clubs and musical societies, generally speaking, are not conspicuous in scholarship. Either music and engineering do not exist simultaneously to any eminent degree in the individual student, or else there is not sufficient time at college to devote to both.

What Mr. Scharff says about the development in the engineer of "some measure of idealism and an admiration for the finer qualities of human nature; a sense of the human relations involved by his place in the social and economic organization of which he is a part; and a recognition of the romantic quality of the engineering work on which he is engaged" cannot be gainsaid. It was mainly in recognition of these *desiderata* that the author and his former partner some years ago compiled the book of "Addresses to Engineering Students" to which reference is made in this address. A professor in any branch of engineering instruction who does not inculcate in the minds of his students such ideas as those mentioned by Mr. Scharff certainly fails in his duty to them and to the institution in which he teaches.

Concerning what Mr. Gregory M. Dexter remarks about the giving of public recognition to the work of one's engineering associates, and the duty of technical societies to "emphasize the qualities of sympathy, integrity, and nobility in an engineer entirely apart from any recognition of technical ability," the author is in perfect accord; and he is glad to see these points thus emphasized. As stated at length in the address, public honors to American engineers are very rare, and it is urgent that this undesirable condition of affairs be changed. The author is disappointed by the failure to discuss his suggestion of the formal establishment of the title of "Dean." The man whom he would have chosen as most worthy of the title of "Dean of American Engineers" was Dr. Elmer L. Corthell, who has since passed to the beyond. In his death the engineering profession of the entire world has suffered a great loss; for, although he had already done much for that profession, he still had many valuable things to tell concerning matters of importance encountered in his unusually broad experience in this and other lands.

Mr. Dexter's proposed slogan of "Every Engineer the member of at least one society" is most commendable; and it should be adopted by our profession. His suggestions concerning helpfulness to subordinates are pertinent and easily followed. If every engineer were to make a practice of adopting them, immense good to the profession would most assuredly result.

To Mr. Gardner S. Williams' objection to the study of Spanish instead of French, German, or Latin, the author would reply that, in his opinion, the time is coming when quite a large proportion of the technical graduates of the United States will do business in Latin-American countries; and that whether the said time is to be close at hand or distant, depends upon how soon and how thoroughly the Spanish language is taught in this country, not only in the technical schools but also in the high schools and other institutions of learning of minor grade. Mr. Williams agrees with the author that the study of some foreign language is essential for a proper understanding of one's mother tongue, but he believes that either French or German would prove more serviceable than Spanish and that Latin gives the best training of all. The author cannot agree with these views; for his personal experience has proved that a knowledge of French is mainly a gentlemanly accomplishment; and the experiences of many of his friends show that German is of practical use in this country mainly to the pure scientists and only occasionally to practicing engineers. The reason why Latin has proved to be the most serviceable foreign language for training is its almost exclusive use for that purpose in the preparatory schools. Any modern language, however, would be just as effective as the Latin. In this respect he believes that there is no difference in value between French, German, and Spanish.

Mr. Williams is quite right in stating that the success of the proposed American Academy of Engineers is dependent upon the character of the men who are chosen for the nucleus. Unless they are of the highest standing, and unless they possess the necessary personal characteristics, the project will prove a failure.

In respect to the licensing of engineers, the author believes that in any case the move would be retrograde, but that Federal license is far preferable to State license—in fact, the latter is absolutely objectionable from every legitimate point of view.

Mr. Charles F. Scott suggests that the main reason for the undesirable conditions in engineering is the newness of the profession. While this is probably the case, engineering has been long enough established as a profession to show its great importance to mankind, and hence the necessity for quickly raising its status to the highest possible plane.

There are several points whereon the author disagrees fundamentally with Prof. Mott. For instance, when he says "If four years of college are too few for certain students to acquire a proper amount of training, there are, I am confident, just as many cases where the four years have proved a detriment, and each additional year of study for such men means a lessening of their capacity to do effective work in the business world." There may be such young men; but if there are, they are not worthy to be included in the engineering profession. The sooner they give up their technical studies and go into trade or some similar calling the better will it be for them and the better will it be for the profession of engineering. We need bright, keen, energetic, hard-working men in our ranks and no others—excepting that there must be men to do the drudgery and routine work; but these can best be secured from the trade schools.

One of the greatest handicaps under which our profession is suffering is that the courses of instruction in many technical schools are adjusted to the capacity of the average student, or even below it, instead of to that of the student of higher ability. It is not fair to men of brains to keep them in the same class with those of decidedly inferior capacity. It might be well, perhaps, to have it generally recognized that certain schools of engineering have very high requirements for graduation, that others are not quite so rigid, and that others are comparatively easy, so that those students who, at the outset, can properly estimate their own ability may choose an institution suited to their tastes and needs. Again, those who fail at any technical school could pass into another in which the requirements are less severe. An objection that might be raised against the practicability of this scheme is that ***amour propre*** will prevent the faculty of a technical school from acknowledging the inferiority of its institution to competitive schools; but if that faculty can bring itself to confessing that the curriculum must be made easier in order to accommodate mediocre minds or to insure a large number of graduates, it surely could learn to adjust itself to the recognition of evident inferiority.

Perhaps the author is somewhat ahead of his time in advocating a large number of high-grade, post-graduate, engineering courses; but he is confident that the time will come when there will be established in this country a great post-graduate school for each of the main branches of engineering, such as described in his paper on "Higher Education for Civil Engineers." Such schools will be found necessary if this country is to compete successfully abroad with the principal nations of Europe, Germany in particular.

The feeling mentioned by Prof. Mott that "an indifferent student once admitted to the freshman class should be given repeated opportunities to maintain standing" is largely responsible for the continuance of low-grade scholarship. It is a mistaken kindness to "boost" an inferior student or to keep in the class one who is mentally unfitted to do the work. In case of illness or any other good and sufficient reason, a bright student who has fallen behind the class should be given an opportunity to catch up; but in the case of one who is chronically in arrears with his work, the privilege should not be granted. Nor is it enough to drop a deficient student to a lower class; for if he is really lacking in either ability, or energy, he should be dropped out of the school, in order to prevent his want of capacity from militating against the progress of better men.

Prof. Mott may be right when he objects to the requirement of the proposed American Academy of Engineers which necessitates that "responsible charge in teaching work must extend over twice as many years as if the work is design or construction:" but he is certainly wrong when he says "It would be quite logical and perhaps eminently proper to exclude teachers of engineering from membership in an Academy of Engineers;" for there are certain teachers who rank quite as high in the profession as the most prominent of the practitioners. It should be observed, though, that all such teachers make it their custom to do considerable practical outside work besides instruction, or else they carry on with their teaching important experimental investigations. In the author's opinion, very few teachers of engineering who neither perform such outside work nor make such technical investigations would be deemed worthy of membership in the proposed Academy. The time spent thereon should, of course, be counted in full instead of being divided by two when figuring upon the candidate's fitness. Prof. Mott says that "it would seem only fair to acknowledge that the work of directing the development of our future engineers is quite as serious business as many lines of engineering activity which are now technically regarded as 'responsible charge'." The author goes even farther than this, in that for at least three decades he has constantly contended that there is no more responsible branch of the engineering profession than that of technical teaching. Years ago the ability of the average instructor in engineering subjects truly did not rank high as compared with that of the average practitioner; but that condition no longer holds, for today the ability and experience of teachers of engineering are much greater than they used to be, notwithstanding the fact that they are paid, as a rule, only about one-half of what their services are really worth. It might clear up this point somewhat to state that the constitution of the proposed American Academy of Engineers was drawn seven years ago, and that a large proportion of the promoters of the project were either professors in various branches of engineering or engineers who had taught technical subjects during portions of their professional careers.

It is not an easy task for the author to discuss the remarks of Prof. Burr, for the reason that, in the main, the professor's idea and his own coincide—still there is an occasional difference of opinion. It lies mainly in the suggested cures for the alleged deficiencies. For instance, Prof. Burr says: "It will be difficult, at least for some engineers, to realize fully what a number of these alleged defective characteristics of individuals can have to do with the status of the engineering profession as a whole." It is submitted by the author that the mass is composed of individuals, and that if objectionable actions and characteristics can be corrected in a large proportion of the individuals composing the mass, the general status of that mass will inevitably be materially improved.

The author does not question the correctness of Prof. Burr's statement that other professions than engineering have many of the defects enumerated, and that such other professions need the suggested improvements as much as does the engineering profession. But the scope of the paper is limited to the improvement of the status of the latter profession only. Again, it does not in any way help engineering to claim that it is no worse off than the other professions. If, however, it be admitted that, on the whole, the various professions are about on a par in respect to standing, is it not evident that if, in any manner whatsoever, the profession of engineering be materially improved, our calling will be advanced beyond the others, and engineers in general will be benefited thereby?

It is unfortunate that "any land-surveyor, locomotive-driver, or chauffeur even, may call himself an engineer;" but the condition exists and cannot well be changed at this late day. Legislation would be powerless to stop this practice; but custom in the coming years may effect some satisfactory modification, so that the term "engineer" will then be restricted to the designation of highly educated, technical men.

There is no denying the correctness of Prof. Burr's claim that "there are many cases of procedure of members of the profession of such character as to fall far below the requirements of any worthy code of ethics, even if such existed." That undesirable state of affairs certainly needs correction; and, in the author's opinion, this can best be accomplished through such an organization as the proposed American Academy of Engineers.

Prof. Burr is absolutely correct in stating that engineers have no proper or adequate code of ethics, and that one is badly needed. Many men would be restrained from diverging from the path of rectitude if they really knew, beyond the peradventure of a doubt, what actions are and what are not legitimate. If, however, such a code of ethics could be established, it would not serve as a cure-all for the numerous defects and shortcomings that exist in engineering practice. It would undoubtedly accomplish much good; but the other methods suggested in the author's paper would also be found necessary, even to approximate at all closely towards ideal conditions of professional life.

It is a matter of deep-satisfaction to the author that Dr. Swain has joined in the discussion of this paper even to the small extent which the limited time of that eminent engineer has permitted; for the general concensus of opinion furnished by the discussions would have been incomplete without his dictum. Concerning his remarks the author has no adverse comment to make, but he would like to emphasize slightly a few of them.

It is quite understandable that too much attention can readily be given in engineering courses to the study of economics and sociology. Such courses are not primary, but subsidiary, although undoubtedly of great importance. They should be taught to engineering students by an engineer who has paid special attention to their study, and not by either a professed economist or a professed sociologist specializing in those subjects, because such instructors too often are prone to lead their pupils to believe that the said subjects are the most important in the entire curriculum. This comment is applicable also to some instructors in other subsidiary courses of technical curricula.

Specializing in economics or sociology by students strikes the author as being very futile, unless, perchance, one intends to adopt as his life's work the teaching of these subjects. Even then, however, he should have a broad, general course in many other subjects in order to be able properly to teach such specialties. The idea involved is comparable to specializing in Sanscrit, Hebrew, or Chinese.

Dr. Swain's summary of the things necessary to advance the engineering profession is admirable and needs but little comment. His mention of the memorial to Alfred Noble leads the author to suggest that some similar recognition should be given to the life and accomplishments of the late Octave Chanute, who was not only one of America's most prominent engineers, but also was the man whose experiments and investigations made possible the aeroplane. It would be an appropriate and worthy undertaking for all the national engineering and scientific societies of this country to do for the perpetuation of the memory of Chanute at least as much as has been done to perpetuate that of Noble.

In this connection it may be of interest to relate an occurrence which took place in Paris about the time that Bleriot flew across the English Channel. The author happened to be there on business at that time; and one evening he was being entertained at dinner by Count Loicq de Lobel, the only other guest being Monsieur Francois Deloncle, *Depute de Cochin-Chine,* a statesman of such prominence that he had just been offered and had refused a position in the French Cabinet. The conversation naturally drifted to aeronautical matters, and as it was about the time that the French Government decorated the Wright brothers the author remarked that they were honoring the wrong men, because it was Chanute who had made possible aerial flight. When asked to explain, the author stated that on account of his long and intimate friendship with Mr. Chanute that gentleman had kept him posted in detail from time to time concerning all the steps that he had taken in his aerial investigations and that, consequently, he (the author) could speak authoritatively upon the subject. He then proceeded to tell the whole story; and Monsieur Deloncle was so interested therein that he made numerous notes in his pocketbook. After concluding them he said: "Please write to your friend, Mr. Chanute, and tell him that I shall see that he receives the Cross of the Legion of Honor in recognition of his services to the science of aerial navigation." Mr. Chanute was greatly pleased when he received the news; but, unfortunately, his early death thereafter and the slowness of government routine combined to prevent the realization of the well-earned distinction.

The author desires to express his unqualified approval of Dr. Swain's suggestion concerning the establishment of a Department of Public Works in the Cabinet of the President, and the including therein of all engineering work of every kind controlled in any way by the United States Government.

This is the logical thing to do; and its accomplishment would not only be a great advantage to the engineering profession but would also effect many benefits and improvements for the American nation. It goes without saying that the Secretary Public Works should be a civil engineer of the highest standing and of acknowledged executive ability.

In completing this closure of the discussion of his paper the author desires once more to thank the members of the Engineers' Society of Western Pennsylvania for the interest they have shown in his discourse, and to express the hope that the paper with its discussions will be widely distributed by that Society among American engineers and the technical press of this country, to the end that the consensus of opinion obtained may prove of benefit to the engineering profession as a whole, especially in the effecting of many desirable and greatly-needed reforms.

THE GLACIAL EPOCH

Physics of the Period, Seismological and Meteorological—Effects of the Period Still Manifest in the Climate of North America

By Thomas P. Roberts*

The subject of the glacial epoch is commended to the attention of thoughtful engineers as a source of mental recreation; not momentary recreation, but of a kind resulting in expansion of mental power and a wider grasp of man's relations with the phenomena of nature in some of her least understood moods. Gigantic and awe-inspiring as these moods may be, they are not so gigantic as the soul which comprehends their causes and divines their ends.

The subject is concerned with such a diversity of physics that so far none of the distinguished specialists in astronomy, meteorology, geology, seismology, paleontology, archeology, anthropology, etc., appear to be able to combine them into a consistent whole.

It has been taken up, it is true, by encyclopedic writers of ability, but gifted as they were, not all parts of their work have shown with the same polish, corners difficult to get at being left untouched.

We have here, therefore, an illustration of a weak point in modern education, the growing minds of our youths being turned perhaps too much towards some specialty which is held before them for their life's work. Nor is the training and education of engineers exempt from this tendency towards exclusiveness in the direction of specialties. Every year we see an increase in the number of journals devoted to specialties.

It can be said of the engineer, however, that no matter whether he is being trained for mechanical, metallurgical, civil, electrical, or hydraulic work, the laws of general physics, that is to say, natural forces, are more thoroughly ground into him than

*U. S. Engineer Office, Pittsburgh.

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THE GLACIAL EPOCH

Physics of the Period, Seismological and Meteorological—Effects of the Period Still Manifest in the Climate of North America

By Thomas P. Roberts*

The subject of the glacial epoch is commended to the attention of thoughtful engineers as a source of mental recreation; not momentary recreation, but of a kind resulting in expansion of mental power and a wider grasp of man's relations with the phenomena of nature in some of her least understood moods. Gigantic and awe-inspiring as these moods may be, they are not so gigantic as the soul which comprehends their causes and divines their ends.

The subject is concerned with such a diversity of physics that so far none of the distinguished specialists in astronomy, meteorology, geology, seismology, paleontology, archeology, anthropology, etc., appear to be able to combine them into a consistent whole.

It has been taken up, it is true, by encyclopedic writers of ability, but gifted as they were, not all parts of their work have shown with the same polish, corners difficult to get at being left untouched.

We have here, therefore, an illustration of a weak point in modern education, the growing minds of our youths being turned perhaps too much towards some specialty which is held before them for their life's work. Nor is the training and education of engineers exempt from this tendency towards exclusiveness in the direction of specialties. Every year we see an increase in the number of journals devoted to specialties.

It can be said of the engineer, however, that no matter whether he is being trained for mechanical, metallurgical, civil, electrical, or hydraulic work, the laws of general physics, that is to say, natural forces, are more thoroughly ground into him than they are into the average collegian. His is a matter-of-fact education divested of theories and speculations to a great extent, nevertheless his facility with figures, algebraic and geometric or the calculus, enables him to weigh almost any proposition which rests upon a basis of practical reason.

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We have many lovers of nature in the profession, even if we have produced no Cuvier, who, from a newly discovered fossil fragment, could build up the entire skeleton. When, however, the engineer visits Northern Siberia and is shown numerous mammoths and other large animals found in full flesh to the last hair on their backs, many of them standing erect, as disclosed by streams cutting into their alluvial banks of half-frozen sand and gravel, he is in a position to ask some pertinent questions, but with as yet no one about to answer them.

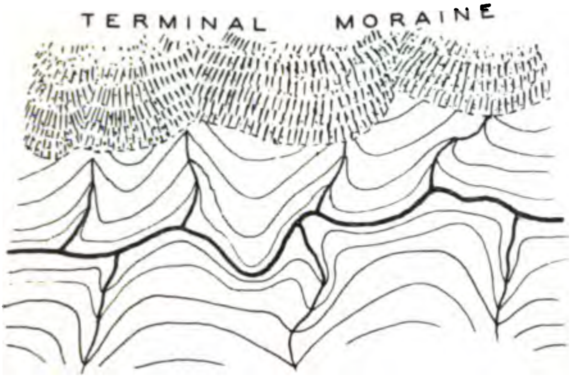
"Why did these animals along the north Siberian coast, as well as in the delta of the Lena River and elsewhere, appear to have died simultaneously, and not fall down when they died? Even lightning would have knocked them down. How does it come that in America and Europe in latitudes far to the south of Northern Siberia the remains of pre-glacial animals are to be found only in the so-called glacial drift in the form of scattered fragments or portions of bones, tusks, teeth, etc., while in Siberia the beasts are found perfect as in life?

"Why are there no terminal moraines over the tundra, or sub-arctic plains of Siberia, and no evidence of an ice cap, if the North Pole was the center of the disturbance?

"Is there any evidence to show when the glacial epoch occurred, not geologically, but chronologically speaking, or reasons for the belief that the causes which brought it about have permanently ceased to act?"

If the "thing" is dead, never likely to return, the practical engineer may think the subject possesses only an academic interest. When, however, he is informed that specialists have demonstrated that fairly civilized human beings existed on the earth before and throughout the glacial period, his humanity is touched, for his great-grandparents may have been among the sufferers.

These mammoths, except for hair upon them and curved tusks, would pass for elephants if driven down Fifth avenue.



OLD CREEK VALLEYS FILLED WITH DRIFT.
Fig. 1.

Surely there is something wrong with our geologists' clocks, for this must have been a yesterday event, and not the hundreds of thousands or millions of years of which they speak.

It is the modern rule apparently to fix the liability of the recurrence of nature's acts far in the future if their occurrence was far in the past, but it is not a safe rule. The flood doctors of Paris thought that as 250 years had elapsed since a real bad flood had occurred on the Seine nature had gone out of that kind of business. They learned differently a few years ago. So with the seismologists who taught in the last generation that old earth was falling off in the intensity of her quakes, when suddenly Krakatao burst forth in 1883 into a volcano as great in display of energy as any three combined volcanoes recorded in history. Then came Martinique, Messina, San Francisco, Galveston, etc., to remind us that there is much discontent remaining in the heavens above and in the earth beneath. Our dear Mother Nature has her same old erratic moods, it appears.

We may, and perhaps really do, understand the causes of atmospheric disturbances in which the sun and axial rotation of the earth are fundamentally concerned, and for earthquakes and volcanoes we say heat, shrinkage, expansion, steam, etc., are responsible, and have rows of books pretending, at least, to explain everything about them.

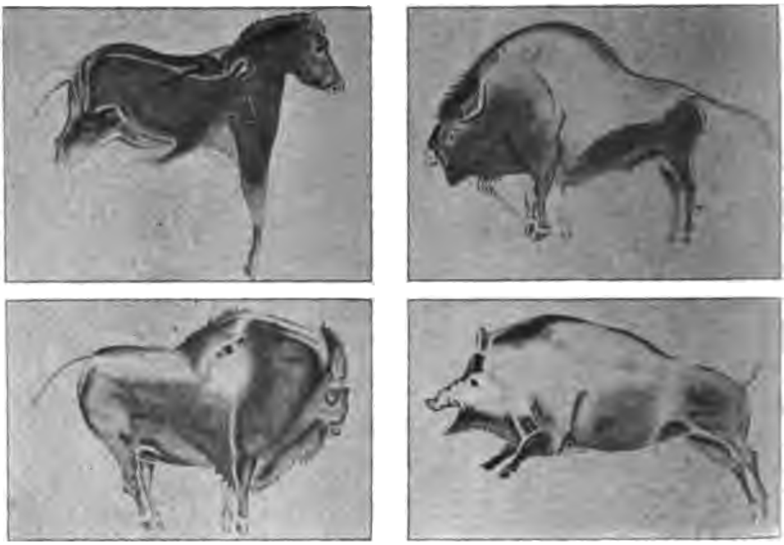


Fig. 2. Animal Types of the Glacial Period from the Altimira Cave, Santander, Spain.

For the Ice Age, however, with seven million cubic miles of ice deposited over Europe and North America, everybody but the engineers claim that that period must have been phenomenally cold. The engineer may say: "See yonder smoke stack? Below it are raging fires. You ask, 'What kind of factory is it?' You may be surprised, but I will tell you that it is an ice factory. So when you tell me there were seven million cubic miles of ice in the glacial ice cap, I will reply 'Old Sol' must have been busy with his boilers to produce it."

Reverting to chronology, Prof. H. F. Osborn, emeritus curator of the American Museum of Natural History, is just out with a book entitled "Men of the Old Stone Age; Their Environment, Life and Art," which is profusely illustrated with photographs of the cave men's art.

The professor was shown the jawbone, "half ape, half man," found in a sand bank near Heidelberg, Germany, some years ago, and concerning which he said: "This is all thus far that we have to show for human history during that vast period of 200 000 years of mild climate that intervened between the second and third glacial waves."

Elsewhere the professor states the *last* glacial period started 125 000 years B. C. and terminated about 30 000 years B. C. That would put his jawbone period back to 350 000 years B. C.

Space and time forbid speaking at length of Professor Osborn's pretentious work, which will doubtless receive the commendation of the anthropological world. Even our able field naturalist, ex-President Roosevelt, has been carried away with it. An unpoetic engineer may, however, have two opinions of the book: First, on excavated bones it is superlatively excellent. Pre-historic skulls are visible things which cannot be ignored; second, for the flesh which covered them and the brains they contained Osborn's illustrations are only the imaginations of a highly skilled artist. Some of the heads are indicative of a high order of intelligence really above the average of modern civilized races. They were artistic people, by the way, nevertheless living in caves and gnawers of bones, which things are rather incongruous. Osborn's theories, so far as they relate to time, will perhaps not long withstand the searching X-ray tests of the real scientists, with whom nothing is accepted as demonstrated that is not coordinated in every direction with its environment.

Osborn has little to say as to causes of glacial epochs, but he does take the greatest liberties with their location and extent. Thus, for instance, he may have glaciers over Germany when they were non-existent in England, or vice versa. The high improbability of great and long-lasting ice fields in juxtaposition with temperate climates never occurs to him. Temperatures in given latitudes are creatures of the winds. Also it seems not to be remembered by him that races of markedly different characteristics could exist at the same time on the earth. We have many examples of their co-existence on the earth even to this day, and we find it sometimes the work of but a single generation, under the guidance of capable teachers, to transform rather low-browed barbarians into good law-abiding people.

It is, perhaps, not too much to say that had the Neanderthal men been taught at schools and given peaceful employment we might have heard of some of them in legislative halls. The measurement of geologic times, by the facial angles of human skulls, none of which are true fossils, are mere speculations, yet it is the present fashion to applaud the anthropologist who pushes back farthest the period of man's existence on the earth. The brain large enough to distinguish right from wrong can be easily taught many other things.

There is no "engineering" objection to the belief that man came from the ape, but there is a decided objection to pushing back the glacial epoch to secure time for the satisfaction of theories of human evolution. Osborn has not a word to say of the observations of the able Swedish Arctic explorer, Nordenskjold, who reports that the soil beneath the feet of the frozen-in mammoths of Siberia, whose lives were extinguished by the initial snow storm ushering in the great glacial epoch, contains recognizable remains of vegetation identically the same as that now existing along the Arctic shores. Nordenskjold also found the remains of such plants in the teeth of other animals which met the same fate as the mammoths (see the "Voyage of the Vega," 1879). The willows, lichens, and mosses, especially mentioned in the account referred to, in some cases are thought to be sensitive to changes, such as cross-breeding, etc., rendering them liable to considerable alteration in comparatively brief times. The present writer holds that these well-preserved Arctic animals are a standing protest against extravagant theories of elapsed time since the glacial epoch.

The unassuming engineer who examines into the age of the terminal moraines in America to determine their period and, not finding a fine old jawbone or works of art in the drift, must take his bearings from what he actually sees, and not from what he thinks he sees. He sees certain valleys filled up with drift, sand, gravel, etc., and the streams diverted elsewhere, but below the terminal what is left of the valley is apparently almost as deeply worn away as other adjacent valleys, which were not involved in any way with drift deposits. Now the latter streams have not ceased to wear away their beds during the 125 000 years referred to by Osborn, and yet there is precious little difference in the elevation of their stream beds from those which ceased to flow 125 000 years ago. The engineer writes in his memorandum book, "10 000 years is nearer the truth than 125 000 years."

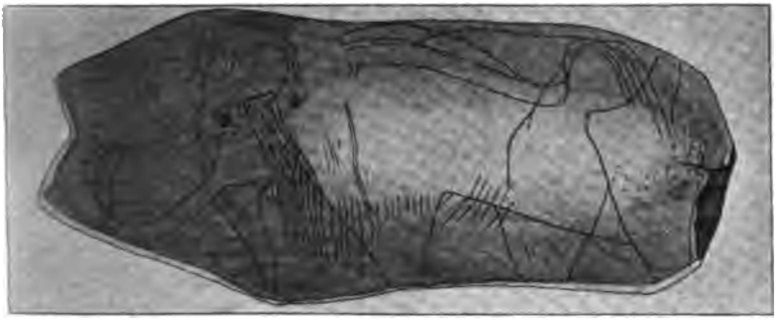


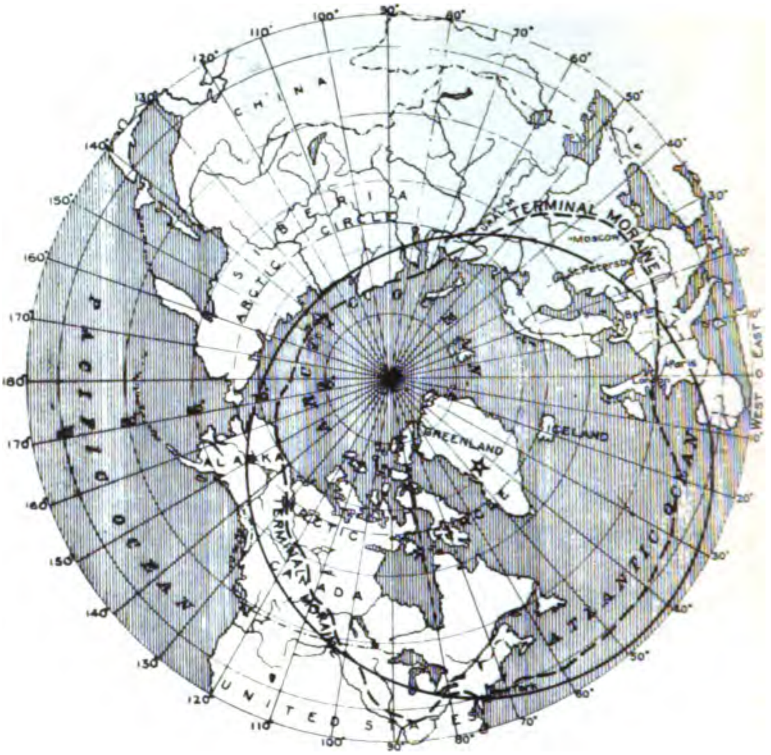
Fig. 3. Hairy Mammoth Incised on Ivory Disc from Dordogne, France, 1864.

Then, as the professor started his last glacial epoch 125 000 years B. C. and terminated it 30 000 B. C., the length of the epoch would be 95 000 years. Now, assuming for the final thickness of the great ice cap 2600 feet, its annual growth, as per the Osborn idea, would be only about one-third of an inch a year. Whereas, taking, say, 5000 years for the ice to form would make about six inches increase per annum. Which is the more reasonable assumption?

Considering what must have been the phenomenally stormy conditions which prevailed in the North Polar regions during the Ice Age, the engineer will feel justified in making a very deep cut into the estimates of time the specialists have figured out.

The engineer has observed frequently that when the dark clouds of winter pass away and the sun shines forth, especially as it does in Canada during the long summer days, the ice disappears much faster than it took to form, very much faster. Therefore, a thousand years might be more than enough to melt the entire 7 000 000 cubic miles of ice. The thousand years besides might be quite sufficient to account for all the phenomena dwelt upon so much by the inter-glacial theorists who number, according to the encyclopedic writers, about one-half of the authors covering the field.

According to the present writer's belief, the glacial epoch commenced most probably about 10 000 years and closed not more than, say, 5000 years ago, or 3000 B C., at a time when civilization was far advanced in Egypt, and perhaps elsewhere,



NORTHERN HEMISPHERE AB. LAT. 35°N
GLACIAL EPOCH
Lines of Terminal Moraines
centering in Greenland.

Fig. 4.

as in Crete, France, Spain, etc., not to speak of Asia, which suffered but little during the glacial epoch. That even the cave dwellers of the Ice Age were considerably advanced in art and familiar with the animal life of pre-glacial times is clearly indicated by the drawings they left in the caves of Spain, France, Germany and Italy. In the Altimera cave, in Spain, more than a half mile from the entrance, on the rock wall is shown a group of various animals covering an area of 45 ft. by 17 ft. The figures had been incised, then filled with pigments, and the sides of the beasts stained red, black and tawny yellow. Let us imagine the case of a class of modern students suddenly called to the blackboards and directed to draw in outline sheep, pigs, goats, horses, cows, etc., the animals most familiar to them. It is to be feared that if the results were submitted to an average cave man for judgment, he would say very justly: "None of the young men were close observers of nature, for she has never produced such distorted, impossible crudities as are shown on the blackboards."

These specimens of prehistoric art from the caves of Europe, to the writer's mind, are evidence of the fact that from the remotest periods man's mind has neither gained nor lost any of its capacity for thought. A. R. Wallace, who died recently at the age of 91, and who was a coadjutor of Darwin in developing the modern theory of evolution, said on his ninetieth birthday that, when he considered the works of the Egyptians of the first dynasty, 70 centuries before our time, there then lived men with brains quite the equal in capacity of Edison, Newton, or any of the master minds of modern times. Of course, the word "capacity" is not to be confounded with "knowledge."

So, therefore, with their God-given capacity, human beings in all periods could not only differentiate right from wrong, but as well appreciate useful things, no matter as to their novelty, or suddenness of invention. The Indians of America could be taught the use of rifles in about five minutes' time, and Wilbur Wright would have received quick orders for flying machines had he met and talked with Alexander the Great about the time the conqueror of the world set sail from the Macedonian coast.

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It is remarkable that there should be such diversity of opinion as to the period of the glacial epoch, a period so recent that many species of existing life, including human beings, are survivors of it. Of the remote past epochs we apparently know more than of this very recent calamity to our fair planet.

Our studies of it are confined to the breaking-up period of the Ice Age, or the search for relics, and so far little has been certainly established as to the cause of the great disturbance.

There is evidence to show, however, that the glacial period was ushered into activity with no premonitions of its oncoming.

Gradual versus Rapid Development of the Ice Cap: The generally received opinion, although not in accord with the writer's ideas, is that the presence of representative species of distinctly Arctic flora, found today in elevated regions well down in the temperate zone, is explainable on the theory of a gradual progress of the ice cap southward from the polar region. Then on the "retreat" of the ice it is held the Arctic plants disappeared, except those which, perchance, found congenial temperatures and soils on the flanks of mountains, like those found at 5000 feet above sea level on Mount Washington, in New Hampshire. This theory is endorsed by America's best known and most indefatigable glaciologist, Prof. G. F. Wright, who is regarded with respect and affection wherever he goes.

The present writer is quite willing to admit that a very long period was required to form the great ice cap which covered more than half of North America and most of Europe with ice to a depth, or thickness, of several thousand feet, and will grant that a very long time elapsed before the ice disappeared. Such admissions, however, do not militate against the idea of a sudden and unheralded arrival in full force of a storm sufficient to obliterate animal life at least over all the territory north of or adjacent to the glacial moraines, except perhaps in regions abounding with caverns, the approaches to which might have been kept open by diligent effort of intelligent beings, as was the case in Northern France along the southern edge of the ice field.

There is ground for great diversity of opinion regarding any aspect of the subject which may be taken up for consideration. Nevertheless, those views most consistent with observed facts and in best accord with natural laws are destined to prevail in the end.

EARLY THEORIES

Writers, in efforts to account for the epoch, have advanced theories of celestial disturbances involving increase of the eccentricity of the earth's orbit, first developed by Dr. Croll and which held the approval of a portion of the scientific world for several decades. Then geologists and meteorologists appeared, and they

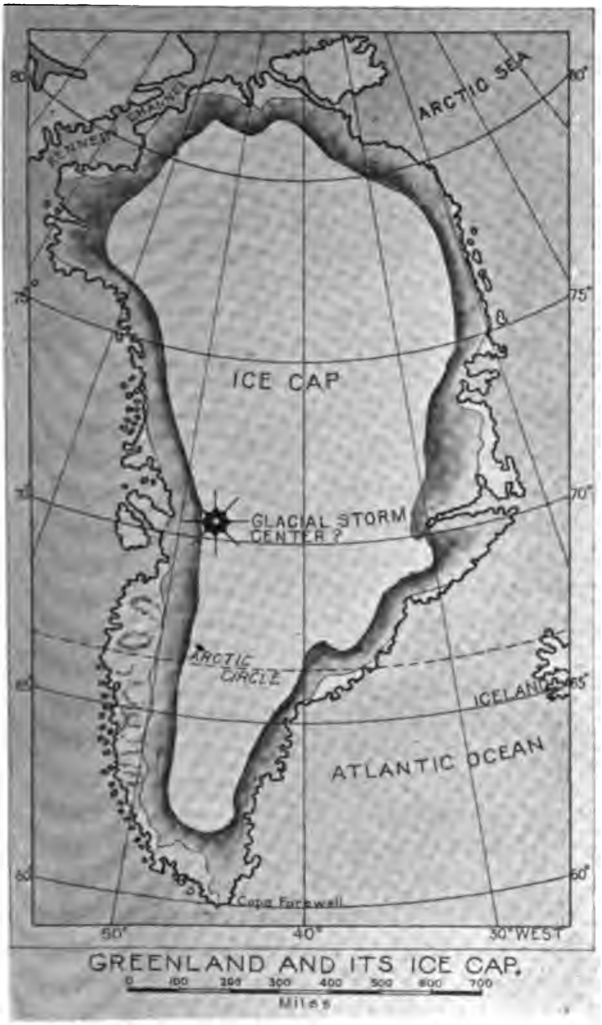
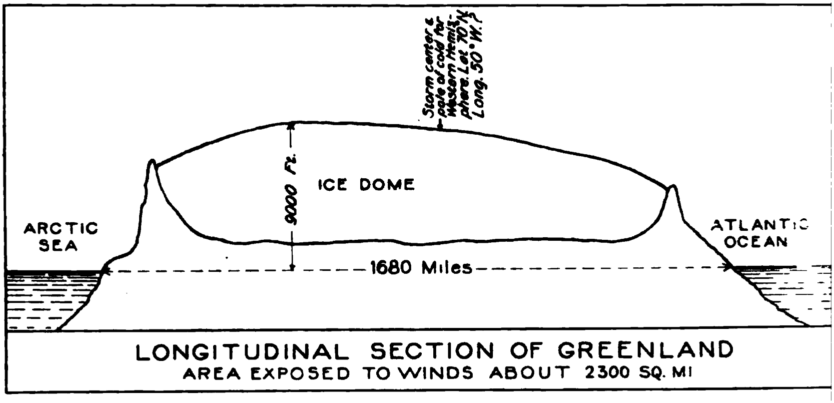


Fig. 5.

have done a vast work in the past few decades in the study of glacial markings and in determining the location of certain prominent "radiant points"—that is, points from which ice masses issued in given directions.


Storm center & pole of cold for Western Hemisphere. Lat. 70°N. Long. 50°W.?
9000 Ft.
ICE DOME
ARCTIC SEA
ATLANTIC OCEAN
1680 Miles

LONGITUDINAL SECTION OF GREENLAND
AREA EXPOSED TO WINDS ABOUT 2300 SQ. MI

Fig. 6.

As it became known that the striations on the rocks left by the moving ice sometimes crossed older markings, different periods of movement were suggested, from which gradually developed much-discussed theories of "interglacial periods" of warmth and cold, or, we might say, of life and death. These studies, however, throw but little, if indeed any, light upon the cause of the disturbance.

In some of the nooks or ravines left from time to time in the terminal moraines having boulder clay beds, trees might have had time to grow, only to be later overwhelmed by some new water and moving ice torrents bursting forth from remote regions where the ice was late in melting. To refer to such movements as indicative of "advance and retreat" and assign very long periods between such outbursts along the terminal moraine, the writer thinks, gives readers erroneous impressions. The Mississippi River is ever changing the channels and bars about its outlets to the gulf, nevertheless the supply of water is constant from its sources.

Most glaciologists, including such distinguished names as those of Wright and Nansen, appear to hold to the belief that the North Pole was the center about which the ice cap formed, and such was the idea of the present writer until a few years ago, when the question arose with him of how to explain the preservation of the Siberian mammoths and other large quadrupeds, now often found intact, erect on their feet, in a good state of preservation, with food in their stomachs. They are found embedded in layers of ice, sand, and gravel in Siberia; while in America and Europe only the teeth, tusks or broken bones of identically the same species can be found in widely scattered fragments.

The idea of plants propagating themselves year by year in advance of an ever-growing glacier, while mammoths and other fleet-footed animals were overwhelmed by the advancing ice field, does not comport with sound reason. The facts seem to point to the conclusion that while the Siberian mammoths were suddenly overwhelmed and buried alive in snow, the ice cap proper never extended itself over them.

In America, however, animals enveloped in the initial snowfall became part of the continental ice cap, which in its final breaking up ground into fragments everything within its embrace.

Line of the Terminal Moraines in America and Europe: The terminal moraines and other visible evidence of the southern limit of the ice cap are on a line about as follows: Starting at the northeast corner of Alaska; thence southward through the provinces of Yukon and Mackenzie to near the northwest corner of Alberta; thence southeastwardly through the lower part of Saskatchewan; thence passing through North and South Dakota in the Missouri Valley; thence through Iowa, Illinois and Indiana, crossing into Kentucky near Louisville for a short distance; thence returning to Ohio eastward of Cincinnati, traversing Ohio near its middle to Beaver County, Pennsylvania; thence northeastwardly to and along the Pennsylvania and New York state line; thence crossing Northern New Jersey to Staten Island; thence crossing to Long Island and bisecting it from end to end, beyond which the line enters the Atlantic.

Taking up the line in Europe, we find it crossing Southern England, Northern France and Southern Germany; thence it continues near the Carpathian Mountains in Hungary into Russia, perhaps passing near Kiev; thence to the east of Moscow, and thence nearly north to where it strikes the Arctic Sea about the Island of Nova Zembla; thence through the Arctic Sea not far north of the Siberian coast to place of beginning in Alaska.

The line through Southern and Eastern Russia is ill defined.

Propotkin quotes the Russian geologist, M. Nikitin, who, speaking of the Ural Mountains, just to the east of the line described, says that evidence of their having been glaciated is "an open question."

As for the general glaciation over Siberia, Prof. G. F. Wright, who made a special tour of that region in 1898 in search of terminal moraines or other evidence of general glaciation, returned with but little evidence to show that the ice cap, supposed by him to be centered at the North Pole, ever extended itself over Siberia. In his lecture on this subject he gave no consideration to the possibility of another center for the ice cap.

Attention is directed to the fact that the terminal lines as described over the lands form, roughly, segments of a great circle centering near the west coast of Greeland, not far from longitude 50 degrees west and latitude 70 degrees north. Taking said point as a center, radials to the terminal moraines or boundary of the known ice cap vary in length from about 2000 to about 2400 miles.

The writer in vain has tried, with the North Pole as a center and with radii of approximately equal length, to enclose the known glaciated areas without producing a circle which would include Northern California, half of China and Siberia in Asia, all of European Turkey, the Balkans, and much of Greece and Italy. These are regions in which terminal moraines of glaciers are unknown except locally about extra high mountains. It is further to be noted that the coasts of the regions above mentioned present no fiords such as are so frequently in evidence along the glaciated coasts of America and Europe.

Among the more recent works dealing with the glacial epoch is Chamberlain and Salisbury's Geology (three volumes, 1906). Readers will find it replete with illustrations of the terminal moraines in Europe and America. Many pages are also taken up with a carefully elaborated theory regarding causes of the epoch, based primarily upon changes in the composition of the earth's atmosphere. In brief, the contention is that the abstraction of carbon dioxide from the atmosphere, and later the carbonation of the water of the ocean, resulted in a general lowering of the earth's temperature. The "prescription" devised by the chemicogeologists for nature was just sufficient to give her a chill, but not quite severe enough to destroy animal life, yet actually favoring some forms of vegetable growth.

The present writer is not convinced of the adequacy of the Chamberlain theory for several reasons: First, it overlooks the importance of heat sufficient to produce vapor which eventually was to become ice; second, it overlooks the possibility of erratic storms moving southward occasionally from the polar region during the epoch of sufficient frequency to deposit snow, which gradually accumulated on high mountain points remote from the glacier field, sufficient in quantity to produce local glaciers, a point referred to elsewhere in this paper.

It is to be admitted that the entire earth at times during the great epoch may have been subjected to storms of abnormal but temporary intensity. It may be claimed also that a study of the evidence presented in vegetable life of the tropics will not warrant the belief that there was a world-wide stunting period in its development during such a comparatively recent period as that of the glacial epoch. As has been intimated in several places by the writer, there is a lack of co-ordination of known facts relating to the glacial period which it should be the duty of engineers to bring about, if possible.

Enormous Volume of the Ice Cap: We may present figures, but it is difficult for us to conceive the volume of ice that must have been contained in the glacial ice cap. It is known to have been 5000 ft. thick around the White Mountains, Vermont, and even more than that elsewhere, where the mountain ranges projected above it high enough to afford a measure. There is reason to think, however, that it accumulated to a greater thickness about high mountains than over the lowlands.

On the assumption that its thickness averaged about a half mile, or 2640 ft., and that the area covered on land was 14 000 000 sq. miles in North America and Europe, we can have some conception of the vastness of its bulk and weight. In bulk it was 7 000 000 cubic miles, which to express in tons weight would almost exhaust the printer's font of naughts.

So much ice would require water in proportion to produce it. Exclusive of the Arctic Sea there are about 185 000 000 sq. miles of oceans from which water was derived by evaporation, to be precipitated in the form of rain or snow, eventually to become ice, which under its own weight would be its final form. To make 7 000 000 cubic miles of ice would have lowered the oceans of the world about 200 feet.

Dr. Croll in his speculations suggested that the weight of the ice cap *about the Pole* would have shifted to some extent the earth's center of gravity and have caused the water of the ocean to flow toward the Pole. Others seized upon this thought to elaborate the theory that the polar regions sank below sea level, at least sufficiently to enable icebergs to float over the country. For the continents to have sunk below sea level would have developed fissures, or lines of rupture somewhere, which would be visible to this day. Greenland and other areas in the far north indicate a recent rising of several hundred feet, but contrariwise, other areas are thought to be sinking like the New England coast, although there is no evidence that any general subsidence of the northern continents has taken place in recent geological epochs. There is no possible doubt, however, that in past geological epochs great portions of the continents rose and fell repeatedly below sea level and to great depths, and this, too, since highly developed animal types came into existence.

The Ice Age was not, in the writer's opinion, a geological epoch, strictly speaking, but was connected more with meteorological disturbances aided, quite possibly, as will be later argued, by ionized dust particles rising from volcanoes in high latitudes.

Temperatures and Storms: There is little or no evidence to show that the temperature over the earth, as held by so many, was phenomenally cold during the Ice Age; at least nothing convincing on this point has been heard from the botanists or zoologists to the effect that life forms in the tropics were materially modified since the close of Tertiary times. In the North, however, there has been witnessed the complete extinction of practically all forms of land animal life within and along the skirts of the glacier-making storms.

These storms must have been persistent in beaten tracks for centuries, causing the semi-tropical conditions in the temperate zones in Europe and America to be subjected to considerably

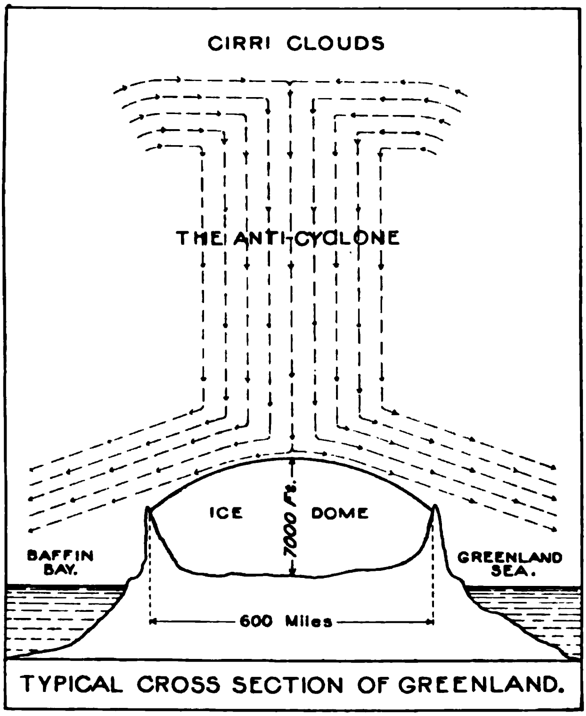


Fig. 7.

colder conditions—a climate no longer congenial to various species of animals which disappeared, doubtless, gradually. By increase, or decrease of temperature, reference is not made to the sun's heat, which the writer believes has been constant at least for a period long antedating the Ice Age. This is not to deny, however, that during the Ice Age the weather in North America and Europe south of the terminal moraines was subject to the effects of erratic storms from the north, *especially cold* during the winter months. There are strong grounds for the belief, however, that the Ice Age resulted in important changes of oceanic currents moving towards, and issuing from, the North Polar regions. The Pacific was closed at Bering Strait by an isthmus connecting the two continents, while the Arctic Sea was much smaller, and but few icebergs in pre-glacial times reached the Atlantic to cool its waters. Hence, with the same emanation of solar heat rays,

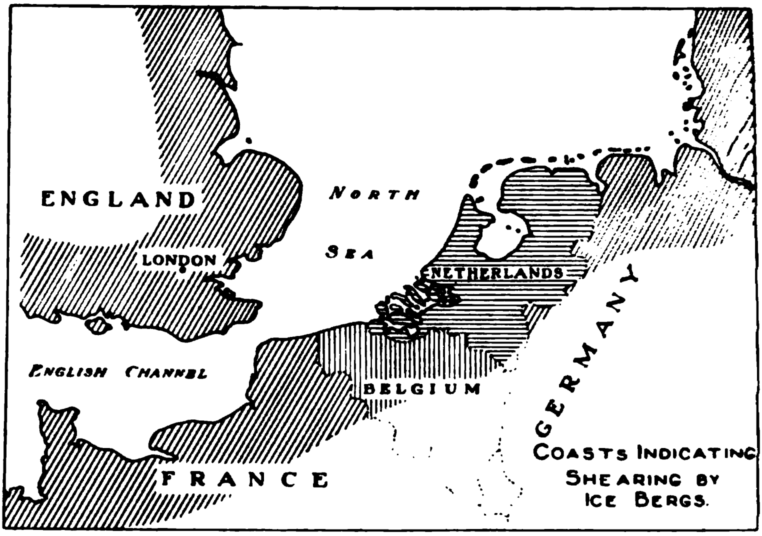


Fig. 8.

the mean surface temperature of the seas in the North Temperate zone was warmer, which warmth would tend to increase evaporation and augment precipitation.

We must be mindful all the while that seven million cubic miles of ice, on a very conservative estimate, had to be made from evaporated water; and to leave the earth and to rest arguments upon the sun is practically abandoning the known to seek aid from the unknown.

The recent glacial epoch was not the first one experienced on the earth, if we can believe the geologists who have reported finding striated or grooved rock surfaces in very ancient conglomerates. It is also to be hoped that in studying the last one, men may find in the future some way of mitigating their resulting miseries; but in any event the ubiquitous animal—man—may be expected to survive on the earth through even worse disasters than he has so far experienced.

The present writer must persist in the belief that the transmigration of Arctic plants during the epoch was the result of their seeds, or fertile spores, being pushed along by the ice, to develop whenever conditions favored their germination.

The Siberian Mammoths, Their Vast Numbers and Food Supply: The mammoths of the period were closely allied in Siberia, Europe and America with existing species of Asiatic elephants, averaging, however, somewhat larger than their southern congeners. They differed from them in being covered with a woolly fur. The writer can refer to an instance of a thinly haired dog, brought by himself from Brazil, which during the first winter in Western Pennsylvania developed a thick fur-like covering. And so it might be with elephants in a far northern climate. The presence or absence of hair on animals is not evidence of generic differences.

The mammoths probably found, as do the Alaska reindeer to-day, ample nutriment, even during the severest weather, in the lichens and mosses, the lichens, curiously enough, being richer in protein than any of their genera of the temperate and tropical regions. Hunters in Norway are reported as living comfortably for months at a time with no other food but reindeer steaks and boiled lichens, while with us the lichens appear to have no food value whatever for birds and animals.

The writer is convinced that such vast numbers of large animals along and above the arctic circle in pre-glacial times must have depended very largely upon this species of plant, and animals will not migrate permanently from good to inferior pastures. Judging by the numerous specimens of their remains which have been found in America in shallow excavations over limited areas of glacial drift, the number of mammoths once existing in the north must have been exceedingly great, the like of which has never been equaled elsewhere, unless we may except some of our western states where formerly numerous herds of buffalo roamed in vast numbers.

The snowfall was doubtless very heavy over much of Siberia; nevertheless the precipitation over regions south of the ice cap, no matter how heavy, could melt at times in whole or in great part, whereas within the regions actually covered by the ice cap the snow and ice kept piling up year by year to a vast height.

The writer is persuaded that the initial snow storm of the epoch buried alive mammoths and all other life forms throughout Northern Europe and America and that large animals preferring to stand erect as the snow packed about them with increasing depth could neither walk nor lie down. Those found in Siberia to-day, therefore, have never been disturbed, whereas those in America were ground to pieces in the final break-up of the great ice fields, as has already been mentioned.

Breaking Up of the Ice Age: The breaking up and disappearance of the great ice pack during the summer seasons at first, doubtless, produced shallow lakes in various localities and of different elevations. Later when the icy barriers between the lakes weakened from melting, fearful floods resulted, the penned-in water seeking outlets to the seas. Then we may imagine great masses of floating ice stranded in the outlets and choking them up, when immediately would result reservoirs of capacities much greater than those of the first lakes. Eventually, the reservoirs would become full of water, only to burst through later in some new direction. Thus can be explained striations on rocks crossing each other without resorting to separate and distinct epochs with vast periods between them.

So it would proceed,—the building of reservoirs, hundreds of square miles in area and hundreds of feet in depth,—until at last masses of the bottom ice would float up, shod with the rocks to which they may have been attached. When these rock-shod bergs acquired rapid motion through gaps in the lake boundaries, they would tear up the shoal places in their course, that is to say scrape the hilltops, and push the debris ahead of them, sometimes to places where it would drop by gravity into valleys and fill them up. Each successive year's inroads into the great ice mass to the north would proceed more rapidly, doubtless, in some areas than in others, no two season's work being alike either in areas covered or work done by the ice and water, the final result being the chaotic conditions of land surface left to us to contemplate.

In one place we find all the original soil carried away, leaving great marshes and lakes over the landscape, whilst elsewhere vast areas of moraines of sand, gravel, and boulders are in evidence, as in southern Michigan, to illustrate. It is, however, idle to speculate on these movements; for hydraulic forces and hydrostatic pressures were in operation, during the breaking up of the ice, on scales inconceivably great, generating destructive forces with which we have nothing to make comparison. How hopeless, therefore, as may be imagined, it is to search in the detritus of America expecting to find more than fragments of bones of pre-glacial animals.

Over some considerable areas the ice cap in all probability never moved bodily, but was melted *in situ,* leaving the original surface undisturbed. Chamberlain and Salisbury in accounting for this absence of marking advance the theory that in such areas the ice may have been only a few inches or a few feet thick. As a matter of fact, had the ice been a thousand feet thick, but had disappeared gradually *in situ,* it would have left no trace of its one time existence.

Temperatures and Snow Fall: Nansen in his writings accepts the North Pole as the storm center of the glacial period, and regarding the absence of moraines in Siberia he states as follows:

> "The Siberian coast is superficially formed to a large extent of frozen soil and gravel interspersed with clear ice, and in this soil the bodies of mammoths and other quaternary animals have been found preserved in a fresh condition by the low temperature. The absence of a glacial period in Northern Siberia is probably indirectly due to the low temperature which prevailed there, which stopped the access of water vapor from without, so stopping the supply required to produce sufficient precipitation to form glaciers or ice caps." (11th Edition Brit. Enc. Art. "Polar Regions").

For some interesting particulars regarding the remains of mammoths references may be made to Lydecker. (See "Mammoth", Brit. Enc. 11th Ed.)

It is quite possible that Nansen never gave serious thought to questions of temperature as affecting precipitation. He was first to cross Greenland and give to the world a description of that great continental island of the utmost interest. He, however, crossed it on a latitude considerably south of northern Siberia yet even colder than that region; nevertheless its cold temperature did not prevent the formation of ice beneath him to a thickness of several thousand feet.

Greenland, Volume of Existing Cap: In length from north to south Greenland measures 1680 miles, with a maximum width of more than 800 miles. Its area is estimated at 827 000 sq. miles, or three and one half times that of Texas, or nineteen times that of the State of New York.

Except for a narrow strip about its border the island is covered with a smooth ice cap which in the north is over 9000 feet above sea level, diminishing to about 6000 ft. near the southern extremity of the island. Mountain ranges must have paralleled its eastern and western coasts, for at many points rocky peaks project above the interior ice field. Numerous spaces between the peaks were valleys at one time, and through them great icebergs now break away from the interior ice mass, reaching the ocean on both coasts through deep firths or fiords. From the coast ranges the surface of the ice gradually rises upon grades of eight to ten feet per mile to the center of the island, reaching elevations much greater than those of the coast mountains.

Nansen describes the winds in the interior as generally moving towards the coasts, and hence he considered the island as forming an anti-cyclonic region.

A region so vast and of such great general elevation, if we except Antarctica, is unparalleled on the globe. If the general depth of the ice on the island walled in by the coast mountains is, say, one mile, its volume would probably equal that of the combined mountain ranges of the world, exclusive of plateaus like Tibet, etc. The broad side of the island presents an area of fully 2000 sq. miles to the winds, so that it is little wonder that barometric lows so rarely, if indeed ever, scale its icy escarpments to spread over the interior. Interesting indeed are Nansen's remarks about the character of the ice, winds, etc., and which have been corroborated and greatly extended by more recent expeditions referred to in much detail by Prof. Hobbs in his paper which appeared in the August, 1915, proceedings of the American Philosophical Society.

Anticyclones Over Greenland: The present writer would have to diverge considerably from the purpose of his paper to enter into a discussion of the many points developed with such painstaking care by Prof. Hobbs, from the records of the latest

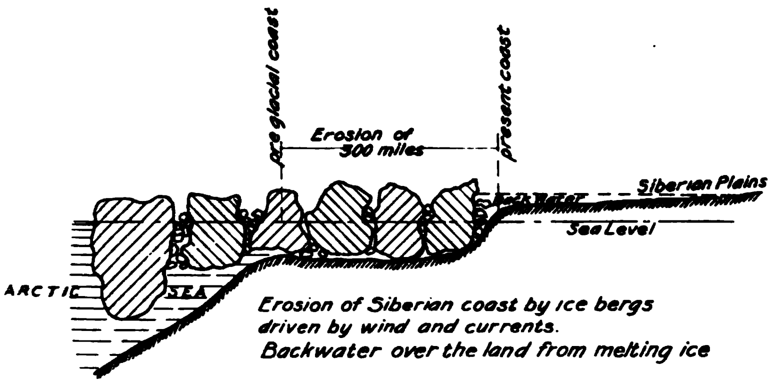

pre glacial coast
present coast
Erosion of 300 miles
Siberian Plains
Backwater
Sea Level
ARCTIC SEA
Erosion of Siberian coast by ice bergs
driven by wind and currents.
Backwater over the land from melting ice

Fig. 9.

foreign scientific expeditions to Greenland and Antarctica. Atmospheric phenomena are described by him relating to the causation of permanent, and of seasonal anticyclones, possibly new to science. Especially interesting it was to note that Hobbs located his chief fixed anticyclone center in Greenland not far from the point on the 70th parallel of latitude where a pin was placed on a globe three years ago by the writer to mark what he considered the dominant center about which generally, but not invariably, the migratory cyclones of much of the northern hemisphere revolve to this day.

Hobbs indicates the existence of another anticyclonic area near the southern extremity of Greenland, and another on the island of Spitzbergen. He graphically expounds his theory of the origin of anticyclonic areas. Regarding the principal one in Greenland, he tells how spicules of ice, or snow, descend (in the center of the island) vertically from the cirri clouds, thence to roll or be blown along by the winds hundreds of miles over the dome shaped ice cap, towards the coasts.

Some of the snow remains to add to the growth of the ice cap, but much of it is eventually blown into the sea, some of it to the distance of 200 miles from the coast.

The radial winds from these continental glaciers are generally constant, and if such be the case the 200-mile rim about Greenland is to be regarded as an extension of the influence of the glacial anticyclone, adding hundreds of thousands of square miles to its aggregate area.

On page 188 of the Proceedings, Hobbs makes the following statement: "The strophic action of glacial anticyclones is one of their most marked characteristics and would appear to be dependent upon the shield-like form of the glacier surface". This statement possesses special interest when a converse application is made of it. Thus, without the swelling or raising of the snow into a "dome" in the great pre-glacial valley of Greenland, no permanent anticyclone could have been maintained over the island. That the great anticyclone there now, is in the way of the free movement of migrating circumpolar cyclones cannot be denied. It was doubtless the case that the ice dome at a very early stage in its development brought about anticyclonic conditions over Greenland.

Let us suppose, however, that the ice dome had not come into being, then this extremely cold center would have been shifted about 1400 miles north, which is to say, shifted to the North Pole. The possible effect of such a change on the climate of North America would, without doubt, have been very great.

That Greenland, Canada, and our northern states had a milder climate in pre-glacial times, one free from blizzards, has been demonstrated in other ways, but this argument drawn from Nansen's and Hobbs's statement, if well founded, possesses peculiar interest.

Only the phenomenal snow storms of the Ice Age, compared with which the storms of this era are trivial, could have filled up the wide, deep valley of Greenland and overspread with ice so much of the earth elsewhere. Very naturally, the first snow falls about the coasts of the island would from evaporation have diminished in depth to some extent, so that with the repetition of this procedure, automatically a "dome' in the central part of the valley would arise, followed by the formation of an anticyclone such as described by Hobbs.

Geographical Changes Made by Icebergs: Mention should be made of the geographical changes made by icebergs during the closing years of the Ice Age, for the bearings the facts may have generally on post-glacial climates.

1. Cutting through by moving icebergs of the former isthmus connecting America with Asia at Bering Straits. The depth there now ranges from 200 to 300 ft.

2. The cutting away of much land and the formation of a great archipelago north of Baffin Land; the islands having in general 300 ft. depth about them.

3. Nansen thinks that the universality of 200 to 300 ft. depth off the Arctic coast of Siberia, for from 100 to 300 miles seaward, represents the area sheared off by the ice. Here was power manifested sufficient to dislodge ordinary rock strata and reduce them to sand, gravel, and boulders.

4. The English Channel cut through. Holland may have been a place of deposit of material left by stranded icebergs. In this connection it is interesting to learn that the ice which scoured away much of the bed of the Baltic deposited marine shells in Germany identical with species still existing in the modern Baltic.

Formation of the Matrix Enveloping the Mammoths: Everything concerning the mammoths is of much interest. Prof. Wright in one of his lectures threw on the screen a photograph of a mammoth almost life size standing erect which greatly impressed the present writer with its wonderful semblance to vigorous life. One could imagine it about ready with one more effort, to extricate its hindquarters from the ice, sand and gravel which enveloped them.

To explain the stratified layers of ice and silt in which the mammoths are found, the following is suggested: Many of the huge icebergs which cut away so much of the low flat land, as they plowed away the coast, must have stranded along the beach. Then the land would be shut off for miles from the sea by almost a mountain of ice. So that when the comparatively warm summer weather came, during the breaking up of the Ice Age, the southern, or landward sides of the stranded bergs would melt rapidly. The water, shut off from the sea, would necessarily flow back over the low land for many miles and form great ponds, and these would often freeze over.

All this water flowing about slowly, rising and falling, freezing and thawing alternately, would result in making layers of sand, ice, and mud and envelop gradually the bodies of the animals without at any time exposing them to a putrefying temperature.

Had there been currents of any appreciable force in motion over the land, the mammoths would have been swept off their feet to disappear forever from mortal view.

The remarkable preservation of these animals affords striking evidence of the fact that at no time during the glacial period, or after, was Siberia submerged below sea level, although some writers assert to the contrary.

Pathway of Storms in High Latitudes: In connection with Prof. Hobbs' paper, already referred to, the writer has received from the Agricultural Dept., Washington, copies of the daily weather maps of the Northern Hemisphere covering the period January-July, inclusive, 1914.

These are the international daily maps fairly started, but unfortunately stopped, by the war in Europe. To meteorologists they must possess great interest in many ways. The daily movements of high and low cyclones following each other in endless succession are very clearly shown on these maps. So also are the temperature curves indicated, unfortunately, however, represented on the absolute zero basis. Greenland at the time, early in 1914, prior to Hobbs's studies of the recent Danish expedition was not a subject of much discussion, which may help to excuse the error of occasionally extending low barometric curves across that island since it is very doubtful if cyclones ever traverse it.

The writer's object in obtaining the maps for study was, if possible, to learn from them to what extent, if any, the Greenland anticyclone controlled the movement of the barometric storms passing over North America and Europe.

There is a dearth of weather stations in northern Canada, so that over a very wide belt to the west and south of Greenland definite information is lacking in regard to the paths of storms near the island. There is positive evidence, however, that none of the migratory storms originating in, or passing through, any part of Alaska, or the Province of Yukon, ever impinge upon the coast of Greenland. These storms, therefore, instead of following parallels of latitude, which would conduct them to the southern part of the great island, almost invariably, especially

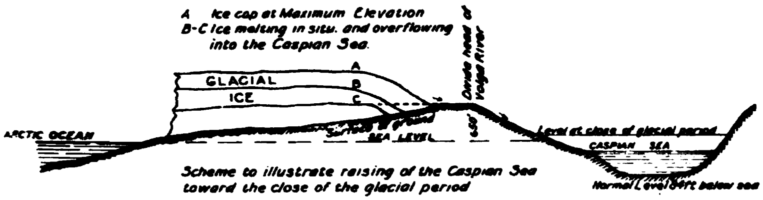

A Ice cap at Maximum Elevation
B-C Ice melting in situ. and overflowing into the Caspian Sea.
GLACIAL
ICE
A
B
C
Divide head of Volga River
ARCTIC OCEAN
Surface of ground
SEA LEVEL
650'
Level at close of glacial period
CASPIAN SEA
Scheme to illustrate raising of the Caspian Sea toward the close of the glacial period
Normal Level 84ft below sea

Fig. 10.

during the cold months, strike southeastwardly to the United States, generally to the west of Lake Superior, and thence through our northern states; thence trending eastwardly and frequently finding their way to the Atlantic via the St. Lawrence Valley or to the south of that valley. There are exceptional storms that dive southward deeply into our country. Then, also, there are Gulf storms sometimes, joining with their Arctic kindred and following them down the St. Lawrence route.

Turning to Eastern Europe and Asia there appear to be no favored storm routes east of west Longitude 20°; Greenland no longer intervenes between the lower latitude and the North Pole and hence with no anticyclone in the way storms appear to trend more to higher latitudes than they do in America. Many of them leaving our coast in latitude 48° to 50° reach 60° north after crossing the Atlantic. Even the Ural Mountains, which present a considerable barrier (2000 to 5000 ft. elevation); appear to afford but little obstruction to the progress of cyclones, yet in this country it is generally thought that the Appalachian range is potent in deflecting storms into the St. Lawrence Valley. Thus it is observable that the Alaskan storms differ from those in Russia in their movements, and that Greenland, rather than the North Pole, is their foci, about which they circle at least from Longitude 140° W. to 20° E.—or nearly half their circuit of the globe.

However this may be, it is of interest to note that many of the storms of the present time traversing America follow the same track which was traversed so frequently by the terrific storms of the glacial epoch as indicated by the terminal moraines.

There is nothing in the configuration of our continent which will furnish a satisfactory explanation of the course of these storms, so regardless of latitude, while most of the time appearing to preserve a comparatively uniform distance from a point in Greenland.

Shifting of the Earth's Center of Gravity: In discussions of the glacial epoch, the writer has failed to see any notice of a certain phenomenon having a possible connection with that period. It was discovered about twenty years ago, in the highly critical observations for latitudes undertaken at Cambridge, England, and Cambridge, Mass., that there was a diurnal discrepancy in latitude, about the 45th parallel, amounting to 40 or 50 ft. In other words, it was shown that the North Pole wobbles to some extent after the manner of a slowing spinning top, while it was thought the south polar axis turned on a fixed point as tops do.

During the glacial epoch much the greater portion of the ice cap rested on the American continent, and such eccentric loading of the earth would necessarily shift to some extent the earth's center of gravity. Thus we possibly have an explanation of the wobbling of the North Pole. In time, therefore, with the disappearance of the cause, this eccentric behavior of the North Pole will probably cease.

Possible Causes of the Glacial Epoch: The following suggestions by way of a summary are presented in brief terms as hypotheses for the reader's consideration:

1. That a point in Greenland rather than the North Pole was the center about which the glacier-making storms revolved during the great epoch.

2. The glacial period was not marked by excessively low temperatures, rather to the contrary, evaporation from the seas and precipitation may have been in excess of present day experience.

3. That to bring about marked excess of evaporation, unusual, in fact phenomenal, and persistent stormy conditions in the far north, must be predicated.

4. That if we assume exceedingly dark and generally cloudy conditions for the low cyclones migrating about Greenland, intercepting much of the sun's light and heat during the northern summers, there would be little, if any, thawing weather on land surfaces within the darkened area, while without said area over the earth, normal temperatures would generally prevail.

5. The proximate cause of these essential conditions, the writer suggests, were frequent if not continuous seismic disturbances in the far north, perhaps markedly so in Alaska, Yukon, Aleutian Islands, also Iceland, Scandinavia, and elsewhere, productive of vocanoes emitting clouds of fine dust, besides lava and mud. In this connection mention may be made of the following:

Recent information regarding an area of approximately 60 000 sq. miles in Alaska covered with volcanic dust, much of it now overgrown with vegetation, therefore, very old. (See recent professional paper No. 95 by David White, Chief Geologist, U. S. Geological Survey). Similar pre-historic volcanic dust areas are found in Yukon. (Brit. Enc.). Largest volcanic crater in Iceland, long inactive. Various records of submarine volcanic activity north of the Aleutian Islands, temporary islands, fogs, and dust storms. Evidence that Greenland appears to be a great wedge-like protuberance rising slowly from a fissure in the lithosphere. Similar uneasy and unsettled conditions of the earth's crust are indicated in Sweden, Norway, and elsewhere.

6. Prior to the glacial epoch the output of icebergs from inland glaciers, as compared with present times, was small indeed, and hence it follows that the influence of the Gulf Stream, and of the Kuro-Siwo, or Japan Currents, surface currents were felt much farther north than now. Such would be conditions favoring evaporation in high latitudes. The enormous loss of water from the seas during the epoch would, besides, result in an acceleration of the velocity of the warm surface currents toward the north. The work done by heat thus sent to the far north was in large part stored in the great ice cap. Allowing 5000 years for the ice cap to form would have lowered the ocean at the rate of about a half inch per annum. The volume lost would have been equivalent to ten times the annual discharge of the Mississippi river.

7. An explanation of the existence during the Ice Age of glaciers in high mountain valleys hundreds of miles distant from the great ice cap seems to be demanded. Thus the Alps (which were very close to the ice cap) the Pyrenees, the Caucasus, and even Mt. Lebanon, Syria (Lat. 34 N.) and in America many high points of the Pacific coast ranges, produced glaciers.

To explain these facts it is suggested that from time to time violent glacial storms from the north were pushed out of their usual paths to become aerial erratics. The requisites for such local glaciers would, of course, be temperatures low enough to freeze rain or retain snow, and on the whole develop more ice in the winters than would melt during the summers.

Some of the Alpine valleys were filled with ice to the depth of 6000 ft. It is to be remembered, however, that these particular mountains were of such height and so close to the pathway of the storms as to be enveloped in the skirts of many of them. The mountains of Pennsylvania, only 2000 to 2500 ft. elevation, lying south of the terminal moraine, at no point indicate that they produced glaciers and as has been stated, even the Ural Mountains, extending from near the Caspian sea quite up to the Arctic Circle, present but scanty evidence of glacial moraines.

8. Ionized Dust Particles in the Atmosphere: The possible effect of dust developing rain or snowdrops from moisture in the air is referred to in an interesting way by Prof. Cleveland Abbe in article "Meteorology" (Brit. Enc. 11th Ed. page 290). Occasional reports appear of dark streaks to be seen in the walls of icebergs. If it were possible to study from a shaft carried down through the ice of central Greenland to its bottom, interesting results might be obtained bearing on the age of the ice as indicated by dust streaks. The only source of dust reaching great altitudes and thence circulating about the earth, is that coming from volcanoes.

While as yet it is not demonstrated that volcanic dust may contribute to the intensity of precipitation there is no doubt that it does play an important part over portions of the earth at times in intercepting heat from the sun. On this subject attention is directed to a recent paper by Prof. Willis L. Moore, late Chief of the U. S. Weather Bureau and now Professor of Meteorology at the George Washington University, appearing in a recent contribution to the St. Louis Star.

Referring to a research made under his direction several years ago by Prof. W. J. Humphreys, Prof. Moore writes: "His search shows that cold weather follows all the important eruptions since 1750, which covers the period for which there are suitable records. We are, therefore, justified in expecting that all future eruptions violent enough to send dust aloft into the stratosphere above storms will have similar effect and that agriculture and many other industries will profit by the foreknowledge thus gained".

Now perhaps we may go further and say in the future—(which it is to be hoped will be a very distant future;)—when we hear that Mt. Hekla and numerous other now quiescent volcanoes in the far north proceed to light their pipes in unison accompanied by widespread seismic disturbances, violent storms, coldness and an uncanny darkness, that another glacial epoch has begun.

It is in Alaska and British America that "blizzards" appear to drop down on the earth then to move over the continent, but as to the cause of this localization of such phenomena we lack knowledge.

Relationship between outbursts of activity in the atmosphere and in the earth beneath our feet is more than suspected. On many occasions a marked lowering of atmospheric pressure as indicated by barometers, has preceded by many hours volcanic outbursts or earthquakes. We might speak of one as the cause and the other as the effect. It is quite easy to show that large cyclones may remove from 100 to 200 billion of tons weight of air from one area and superimpose it on an adjoining area and do it quickly. Such alternations of loading over parts of the earth where the crust is in a state of unstable equilibrium may set up apparently slight earth waves or vibrations, which if suddenly checked in their direction by a contrary force put in operation by some secondary high pressure storm, result in a shock which may prove destructive.

No portion of our globe perhaps is more unstable than the North Polar regions, including with them the strings of islands in the North Pacific down to latitude 30° north. It remains to be determined, however, whether subterranean forces, that is to say heat, or electric activities, are not primarily concerned with the whirling storms of the atmosphere. It is the case that whatever heat or energy is represented in the vapors of the atmosphere is derived by radiation from the earth. It may be objected to that said heat is simply that arising from the earth's surface as warmed by the sun, but still it may not all be derived in that manner. It is also to be remembered that violent storms are, if anything, more frequent during the polar winters than during the seasons of maximum warmth.

Perhaps with delicate thermometers placed in the bottom of very deeply drilled holes with readings by means of insulated wires to indicators at the surfaces, we might discover a new factor useful in determining not only problems in seismology, but also in meteorology as well.

DISCUSSION

Mr. R. R. Hice:* I enjoyed the paper very much; in fact, I do anything about glacial geology. The study of glacial geology is of great interest to me and of very considerable importance to the engineers of Pennsylvania. Really, it is of much more importance than most of you realize. I cannot say that I agree with everything that was said. I do not think the present opinion of glacialists is altogether as given. I do not recall, for example, any of our modern American glacialists—and our American glacialists are away up in front, because we have more glacial geology than they have on the other side—who think that the North Pole is the center of accumulation and dispersion. That may have been true in early days, but the evidences that have been accumulating in recent years point far otherwise.

I hardly know what I can say, because the subject is so large. It is one that cannot be covered in an ordinary evening. Perhaps the best thing I would do would be to make a little statement of the present beliefs and holdings of the glacialists as we have them in this country. We think of the amount of ice as being great. Well, it was great, and yet the total amount of ice at any one time during the glacial period, compared with the amount of ice that we have today, was smaller than are the semi-continental ice sheets, such as the Antarctic ice of today, compared with the mountain glaciers which form the basis of all our studies on glacial geology.

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Now in any theory of the glacial period, we have to consider that the last Ice Age is no isolated, peculiar phenomenon, because we have had a number of Ice Ages. In India we have one in the Cretaceous Age. In the Connecticut Valley, where we have records of one of Jurassic Age. In South Africa and Germany are evidences of Ice Ages in the Permain Age, and in China, Canada and Australia in the Cambrian Age. In fact, we have Ice Ages all along through geological time, and any theory we take to account for the last Ice Age must fit the conditions that existed at those other periods.

Of course, when we speak of the Ice Age, we always speak of the last ice advance. It is, of course, impossible to follow the development of glacial geology altogether, but glacialists in North America almost universally believe that we had two centers of accumulation and consequent dispersion, one known as the Keewatan, and the other having its center in Labrador. At times the outflow of these two centers coalesced, and at times the outflow was from one and then from the other. And the same thing was true in Europe. The center of dispersion over the most of Europe was undoubtedly Northern Scandinavia, and we have no reason to believe, when everything points otherwise, that the ice advances in Europe and in America were necessarily simultaneous, nor the ice advances in the southern hemisphere and the ice advances in the northern hemisphere at the same time. Confining ourselves to North America, we find at the close of the Tertiary period, conditions were very different from what they are today. Going to the mouth of the St. Lawrence River, we find the channel of that stream stretching across the banks with a depth of over 6000 ft. The same is true at the mouth of the Hudson River. The Hudson Bay is part of the basin of now submerged streams, and the streams flowing into the Arctic Ocean all over North America and across Siberia and Europe have all been submerged in recent times, showing that the elevation of the land in very recent geologic times was very much higher than it is at present. In addition to that we have reason to believe that the streams flowing from the Baltic emptied into the ocean farther north. This change in elevation that takes place along the ocean takes place similarly in the interior of the continent. We have means of measuring it in only a few places. The erosion which takes place from high areas, carried by streams down to the seashore, cannot help but result in change of elevation, the higher portions rising relatively and the seashore sinking. We have evidences of this in a great many places.

Now we need no other cause for glacial periods than these higher elevations. An elevation of a large area of a great deal less than the 6000 ft. at the mouth of the St. Lawrence will bring us into a glacial period. The theory of Chamberlain and Salisbury that was referred to is based upon the fact of the elevation of the land, a greater amount of material being thus exposed to the action of carbonic acid and oxygen. We need not, however, fall back to this idea, because the elevation of the land is sufficient to account for all the phenomena of the glacial period without bringing into play other theories.

This elevation being a known fact, we have in that a cause sufficient for the production of an Ice Age, and of each and every one of them. And we must certainly believe from it that we will have accumulations of continental ice in the future. Not necessarily in the north or in the south, but they may occur in other parts of the globe, in the tropics just as well as in the polar regions.

Just here let me refer to Asia. Asia is not glaciated. Why? Because of the land conditions at the time of the ice age. The relief of Asia was vastly different from the present. The mountains are late; they were thrown up at a very late date, and at the beginning of the glacial period there was a direct water connection of the Arctic Ocean down to the Caspian and the Black Seas. There was not the great elevation at that time in Siberia that we had in North America.

To the engineer the points of interest in the glacial period are important. They only affect the engineer from the phenomena which attended the margin of the ice. The Ice Age is not simply an accumulation outflow, standing at a maximum period of development, and a gradual withdrawal, but it was a very complicated time as far as the flow of the ice was concerned. At times the ice flowed from one center and then flowed from the other. We know, for example, that in Pennsylvania we had at one time ice which came from the Keewatan center, because it brought with it native copper from the Lake Superior regions. On the other hand, we know at other times the ice came from the Labrador region and crossed the Mississippi Valley—not generally, but at times. When the ice was advancing in Pennsylvania from the northwest, undoubtedly the Labrador center was not so active, and vice versa. So we have different stages in the glacial history, when the ice advanced from one center to another, followed by a withdrawal to a greater or less extent, perhaps the total disappearance of the ice at times, and then a readvancement. In the Mississippi Valley we have a number of these advances which can be definitely separated. Here, however, we only know of two. We have no record of any others. One was synchronous with the last advance in the Mississippi Valley, known as the Wisconsin stage. Perhaps those terminal moraines are only so great because they are so recent. The other corresponds with one of the earliest advances in the Mississippi Valley, known as the Kansan. Perhaps here we can properly call it an interglacial period, because the difference between the Kansan and the Wisconsin embraces all the time that was occupied by the advance and retreat of a number of stages in the Mississippi Valley.

Preceding the Ice Age in this part of the country we had a very different looking region. At that time the Great Lakes did not exist. We know that absolutely. Their valleys were drained by a great river system. Thirty years ago Carll, from his investigation in the upper Allegheny region, showed that that region in pre-glacial times drained into the Erie basin. Following that it was found that the central portion of the Allegheny likewise drained into the Erie basin through French Creek; and we know that the lower Allegheny at that time flowed southwardly in its present direction to Pittsburgh, where it was joined by the Monongahela, and combined they flowed northwest by the present Ohio to the mouth of the Beaver, and there they were joined by a stream which rose in the highlands of Southeastern Ohio, and the united water flowed northwardly by way of the Beaver

Valley into the Erie basin. The elevation of that stream about Pittsburgh was much higher than at the present time.

The water of the Erie basin emptied into the Ontario basin through a channel west of the present Niagara River. Then it was joined by a stream which drained the upper lake region which flowed across from Huron into the Ontario basin and discharged by way of the St. Lawrence River. The evidences of the flow of these streams is quite clear. I do not have time to go into it.

The stream which flowed up the Beaver Valley was blocked by the ice coming down from the north; the first ice and the water accumulated in the valleys into a great lake, until it overflowed over the lowest divide into the next adjoining basin. And the same would take place in the upper Allegheny and French Creek, etc. When Kansan ice came down from the north that first time an immense mass of morainic material was brought with it, and that held these lakes until they carved the divides between these different river systems and established the Ohio River in its present course. You must remember that the amount of water flowing at that time through those lakes would have not only the ordinary rainfall and snowfall of that time, but also enormous quantities of water coming from the melting glacier. Even when a glacier is advancing from the friction of the moving ice the amount of water that will be discharged is almost beyond comprehension, so that the time required for the cutting of the channel is not so great as we might otherwise think. We know that the cutting was relatively short from the character of the channel cut. It is narrow, precipitous, and there were no meanders of the stream, and almost all the smaller branches did not have time to cut their beds down to correspond to the level of the low channel. That drainage continued in that way until the channel had been scoured below its present level, in some places as much as 200 feet. If we examine the character of that channel closely we will find evidences in the inner gorge that either there was a difference in the elevation of the land or there was a difference in the amount of volume of the water, probably both.

When the Wisconsin ice came down we find very different conditions existing, because there was open drainage to the south and there was freer discharge of the morainic material brought down by the ice. The Wisconsin ice brought enormous quantities of morainic material. We have it deposited all along our streams to a height of 120 feet above present stream level. Strange to say, the material is finer down at the bottom of the inner gorge than it is as we come up. It is pure silt in the extreme bottom and grows gradually coarser as we come to the surface, until it becomes bouldery. Just why that is, I do not know. That is how we obtained our gravel terraces. The work of the streams has been cutting down those terraces and it has crossed the benches of which I spoke at different places. This is the cause of the rapid fall of the Beaver from the upper end at Beaver Falls to the lower end at New Brighton. The stream was cutting across one of those old benches and not following the silted channel.

Now just a word about the age of the glacial period. We have a good time piece for part of it, and that is Niagara gorge. We all know that the work of cutting the Niagara gorge has been limited, too, since the waters of the present Lake Erie cut through there, when first the ice withdrew sufficiently to allow the water of Lake Erie to empty into Lake Ontario. Take the present rate of retreat of the gorge and the present volume of water and the present fall, and we find that the gorge would have required about 8000 years to cut. We know, however, that the amount of water flowing through the gorge has varied. At first it had only the drainage of Lake Erie. Afterwards it had the drainage of the upper lakes. Then there was a period when the upper lakes discharged directly into Lake Ontario. In addition to that, we know that the amount of fall at Niagara gorge has varied, because the level of Lake Ontario has not been uniform. When you take all these things into consideration the late computations of several special students is from 38 000 to 40 000 years, it is remarkable how closely they agree, and we can fairly say that it is 38 000 to 40 000 years since ice freed Niagara.

We have other evidences bearing upon that point. For example, we know that it has been 10 000 years since Lake Ontario has been at its present level. We know that at Toronto, because from certain works in connection with the harbor it has taken 10 000 years at the present rate of deposition to deposit the Toronto bar.

If 38 000 years is the age of the Niagara gorge, we must add the time for the retreat of the ice from its extreme border to give us the time lapsed since the Wisconsin invasion reached its most southern limits. We know that in this time of retreat the ice paused for rather long intervals. We have on the southern shores of Lake Erie, for example, a series of well-formed benches which lie above the present lake level. When we examine these benches we find they shade into well-defined recessional moraines at their eastern ends, showing the waters which formed them were prevented from outflowing towards the Atlantic by the presence of glacial ice.

When we take into consideration all these evidences, it is clear that not less than 100 000 years have passed since the maximum development of the Wisconsin ice sheet. The interval between the earlier Kansan ice and the Wisconsin ice is marked by the time required to cut down the cols which separated the several pre-glacial drainage basins. This time we have as yet no accurate means of fixing, but certainly it is within the limits, if we place the Kansan invasion at 1 000 000 years ago.

The duration of geologic time is not fixed by fossils, but by evidences often of an engineering character—such as the cutting of Niagara. Forests have the same age as the deposits where found. The remains of early man are proper fossils. Finding them in unconsolidated rocks does not alter their fossil character.

The tundra is not confined to Asia, but is found also in Europe and in North America. It is confined to those portions of the continents looking toward the north which were never glaciated. The ice of the tundra, according to Tarr, is not of a greenish or bluish color, as is always the case with glacial ice, but is yellowish. Students of the subject do not think this ice was ever in motion, but that it marks slow accumulation in place, without such elevations as would cause outflow. The ice is interbedded with soils.

When we consider that the Himalayas are of Quaternary

Age, and that large areas of Central Asia were water covered almost to historic time, and the great changes that have taken place in the climate at Asia in historic time, we at once see that the climate of Northern Asia, at a time which must correspond, at least in part, with the ice outflowing in North America, must have been much warmer than the present. This has long been recognized by geographers.

We have no reason to think that the storm tracks in the past were the same as at the present. With the closing of Bering Strait and the rising of Northern America with the islands of the Arctic there was not the great outflowing of cold water as we have today. This necessarily allowed the Gulf Stream to flow in a more northerly course, a fact attested by the character of the fauna preceding the Ice Age. The loss of land in the North is not the result of wearing away by ice action, but due to the sinking of the land. The true continental border of Siberia is found 100 to 300 miles north of the present shore line—this means the tundra is found 200 to 400 miles south of the true continental border, and is not a shore phenomenon. How thick the tundra in Asia may be we do not know, but it has been penetrated 200 feet in Alaska.

DR. A. E. ORTMANN:* To what Mr. Hice said about the conditions which brought about the glacial period I want to add a few words. Colonel Roberts mentioned in his paper that it was not so much the extreme cold which produced the ice period, but the amount of precipitation, and that is quite correct. You imagine that a mountain or continent of a certain elevation has a certain amount of snowfall. When this snowfall in winter is so great that the heat cannot remove it all in summer and there is snow remaining all through the summer, and then comes the winter with more snow on top of that, you have a slow accumulation of snow which, under weight, turns into ice and begins to move as a glacier moves. The question is how can we bring about a precipitation in Labrador so great that it will not melt in summer? It is easily seen that elevation can do that. It is a well-known meteorological principle that precipitation increases with elevation, and the reason is that all air which blows to an elevated

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country has to go up, and air going up expands and cools off, one degree for about 300 feet, and it is a well-known principle that cold air cannot carry as much moisture as warm air, and warm air cooling off must drop the excess moisture so that it begins to rain or snow.

Thus simple elevation of land will produce a greater precipitation, and finally we may arrive at the condition where more snow falls during the winter than is removed by melting in the summer, and in that way the conditions will bring about glaciation.

This may come about any time, as soon as the country is elevated to the proper height. As Mr. Hice told you, we may have it in countries which are tropical. The indications of glacial movement in South Africa are that the ice came from the North and not from the South, as we should expect.

I want to say a few words about what Colonel Roberts said about the mammoths. It is remarkable that we find in Siberia these mammoths preserved entire with the hair on the body. But we must not think that that is a very common occurrence. Of a mammoth found standing upright, to my knowledge, there is only one. We have found some others with the skin that have been mounted. But the first one was not found standing up; it had fallen down. Several other complete carcasses have been found, but not preserved because they were not found by white men, but by the native Mongol tribes in Siberia.

We also have in Siberia scattered remains of mammoths, but we have probably remains of as many mammoths in North America as in Siberia. In America they are scattered and broken up, yet we have complete skeletons, mostly of the mastodon, not of the mammoth, the form which seems to have been more abundant in North America.

The reason these Siberian mammoth carcasses are preserved to the present time is probably due to the fact that the mammoth lived in Siberia in about the same climate as there is there now. The meteorologist calls it the continental climate. The continental climate prevails in those countries which are far back from the sea, and the chief characteristic is lack of precipitation. Consequently, we have in Siberia in winter much colder weather than other parts of the Arctics.

The coldest place in the world is not at the North Pole, but in Siberia, and not at the north shore, but a good way inland; and although it is so very cold there is very little snow. There are large rivers which wear away the banks and there are large bogs, and it is likely these mammoths got mired. The characteristic attitude of the mammoth which was standing upright is extremely interesting. It is in the attitude of sinking back into the mud or quicksand and trying to clamber out, struggling to get out. The whole business froze, and it was not thawed until the present day.

It is interesting to know that at about the time the mammoth lived there, there was about the same temperature that we have today, and there is no evidence whatever that there was in Siberia any glaciation, and this is due to lack of precipitation.

Now this brings us back to where we started, that is, the chief cause of a glacial period is increased precipitation, and since Siberia had no precipitation it had no glaciation.

PROF. HENRY LEIGHTON:* This paper and its discussion have proved most interesting. I might simply emphasize what Mr. Hice has said regarding the length of the glacial epoch. The concensus of opinion among those who have made a thorough study of the subject is that the last retreat of the ice took place about 30 000 years ago, this calculation being founded upon various data, including the erosion of St. Anthony's Falls and Niagara Falls, the erosion of Scarboro Cliffs near Toronto, the formation of Toronto beach, and other interesting data.

The interglacial periods are believed to have been much longer than this postglacial time, and much trustworthy data have been collected regarding their time limits. The entire period of glacial action has been conservatively placed at 450 000 years, with the probability that it was much longer than this. Of more practical interest to the engineer are the effects of glaciation. Engineers who have worked in the northern states among the glacial deposits cannot fail to be impressed with the profound influence which the deposits have had upon man. They have furnished him in many instances with rich soil; they have furnished valuable sand, gravel and clay deposits; they have, by obstructing drainage, empounded water into lakes which can be used for water supplies or for transportation. The engineer interested in transportation finds that the Great Lakes, the Erie Canal, parts of our own projected canal to Lake Erie, have in part utilized glacial channels in their location. The engineer interested in water power will note that most of our numerous northern water falls owe their existence to glaciation, and that the enormous development of water power from the New England mill towns to Minneapolis is the result.

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Over against the benefits of glaciation, the engineer who excavates in glacial country will find that the glacial drift presents many disadvantages. It covers up irregularities in the underlying rock surfaces and fills old pre-existing valleys with drift. These so-called buried valleys are a particular nuisance in some districts, the classic example being those found during the excavating for the Catskill Aqueduct, the new water supply for New York City. To cross some of these deep drift valleys it was necessary to sink deep shafts, until a tunnel or inverted siphon could pass under the valley in solid rock. Glacial geologists were employed to advise with the engineers during these operations.

DR. CHARLES R. FETTKE:* Most of the points in connection with Mr. Roberts' paper on "The Glacial Epoch" which I had intended to discuss have already been taken up considerably in detail by the gentlemen who have preceded me. There are one or two, however, to which I might add a little.

In connection with the last glacial epoch, there has been some speculation among geologists as to whether or not it has come to a final end or whether we are simply living in an interglacial stage at the present time. Most of the interglacial stages, as calculated by glacial geologists, covered intervals of 100 000 to 200 000 years, while the time which has elapsed since the last ice sheet began to melt back from its terminal moraine, according to conservative estimates, has been placed at only 20 000 to 50 000 years. There are still remaining such large ice sheets, as those covering Greenland and the Arctic continent; in fact, these ice caps still have about one-tenth the area of the original continental glaciers, which extended over Northern North America and Europe during Pleistocene time. These regions were not covered by glaciers during the geological periods which shortly preceded the Pleistocenes, for plant remains indicating a mild to semi-tropical climate are found in strata deposited during Tertiary times in Greenland. Evidently no glaciers existed on that island during that period.

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Also, during some of the interglacial stages, the climate was milder further to the north than it is today. Fossil remains of plants are found in some of the interglacial deposits in the vicinity of Toronto which do not grow north of the Ohio River at the present time. Evidently the climate was warmer during that particular interglacial stage at Toronto than it is at the present time. Likewise, from fossil remains found in interglacial deposits in England, it is learned that the lion and hippopotamus were able to live in that country during intervals between the retreat of one ice sheet and the advance of another, while today the climate is not sufficiently warm.

There is, therefore, a bare possibility that we may be living in an interglacial period at the present time, and that there may be another advance of the ice before the Pleistocene glacial epoch comes to a close.

The explanation of the causes which have brought about extensive glaciation over the earth's surface has puzzled geologists for a long time and a great many different theories have been evolved, some of which have been called to our attention tonight. It is definitely known at the present time that there has been more than one of these periods of glaciation, as large ice sheets have developed on the earth's surface at various times during its past history, separated by vast intervals of time. At least four such periods of glaciation are now recognized by geologists,—one during the middle of the Proterozoic Era; one at its close or during the early part of the Palaeozoic; one at the close of the Palaeozoic Era; and finally the last or Pleistocene glaciation.

All of the periods of glaciation either followed or accompanied periods of extensive crustal movement on the earth. Extensive elevation of large portions of the continental areas, therefore, appears to be one of the causes that bring about glaciation. The higher altitude and resulting colder climate are not the only factors which cause this, but such elevation brings about a change in the atmospheric currents and the directions in which the winds blow, as well as a disturbance of the oceanic currents. Whenever the continents stood low and the seas overlapped extensive portions of them, geologic records indicate that the climate was uniformly mild over the entire surface of the earth; while when the continents stood high, colder climates prevailed, frequently, although not always, accompanied by glaciation.

All of the phenomena associated with glacial epochs cannot, however, be explained by elevation alone. The crustal movement at the end of the Tertiary period probably explains the pleistocene glaciation of the Quaternary, but the various advances and retreats of the ice sheet, with the accompanying interglacial periods when mild climatic conditions prevailed as far north as Toronto cannot be accounted for by elevation alone, unless we assume that for some reason or other the North American continent kept bobbing up and down during the Pleistocene epoch. There is no geologic evidence for this.

In this connection Prof. Ellsworth Huntington, of Yale University, has carried out some interesting research on changes of climate and their causes. He has shown that weather conditions have not been constant over the earth's surface even within the history of man.

For example, the climate has been such in the past that great civilizations were able to develop and thrive in portions of Asia where desert conditions prevail today, so that only a very scanty population can eke out a bare existence. The same holds true of our own Southwestern United States, where portions of New Mexico and Arizona, which are practically uninhabited today on account of their arid climate, at one time supported a considerable population, as evidenced by the numerous ruins of prehistoric dwellings.

Huntington's studies have led him to the conclusion that these changes in climates are brought about largely by variations from time to time in the amount of heat which is radiated out by the sun. During periods when sun spots are abundant that body is radiating out more heat than ordinarily. As a result, more heat reaches the earth's surface, which, therefore, becomes hotter. This sets up air currents, however, and storms follow. At such times heated air is constantly rising from the earth's surface into the upper atmosphere, while colder air takes its place. Therefore, more heat is lost than ordinarily and the climate on the earth actually becomes colder.

During periods of frequent storms evaporation is also greater over the surface of the oceans, and more moisture is thus carried inland to be precipitated. As Dr. Ortmann has already stated, the amount of precipitation is an important factor in the production of glaciers. Large portions of Siberia would be covered by glaciers today if sufficient precipitation occurred in that region.

It is possible, therefore, that variations in the amount of heat radiated out from the sun and their resulting influence on the climatic conditions prevailing on the earth may have been a factor which played an important role in the production of some of the phenomena of the glacial epoch.

MR. HARRY J. LEWIS:* Whenever we get to theorizing on the warm interglacial periods, the temptation is strong to consider Croll's combination of high eccentricity of the earth's orbit and the precession of the equinoxes, by which the northern hemisphere, for instance, could swing from warm climate to cold and back again in a full cycle of 23 000 years. Both of these are established astronomical facts, and their combined influence might produce the alternation of a heavy ice cap on land areas turning to semi-tropical conditions much further north than anything we know at present. It is also probable that the ice caps were mostly on the land areas, as the ocean currents would tend to prevent the formation of as much ice along the coast as inland and would also carry away in icebergs the feet of the glaciers that reached the shores. A little study of the southern limits of glaciation in both hemispheres will suggest the tendency of ice to accumulate further south on high ground inland and to drop away to the north along the shores. Nearly all of our great coal formations seem to have a rather wide spread, and consistent conglomerate area somewhere near them in geologic time and glaciation seems to be a fairly probable origin for great accumulations of gravel. Floating ice in shallow water would also be a possible and rather natural agency for the approximate leveling of the areas on which the coal fields were laid down. With the ground thus prepared for marshy conditions over wide areas an alternation of warm moist climate seems to be the most reasonable explanation for a growth of vegetation so rapid that it outran the destructive agencies until it was sealed over and preserved in our coal seams of today.

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MR. THOMAS P. ROBERTS:* Mr. Hice can see no reason to think that the storm tracks of the glacial epoch were the same as those of the present time. The author thought he had presented fairly convincing evidence on that point. Mr. Hice further appears to be wedded to the belief that glacial periods are generally the result of elevation of the land, etc. Being also a believer in numerous interglacial periods, it is difficult to understand how the animals and human beings could have continued their existence through such radical constant changes of the lithosphere and preserve their specific characteristics to the end. The author would invite Mr. Hice's special attention to Prof. Hobbs' demonstration of the origin of ice domes and to the far-reaching effect of anticyclones developed over them. Such study might disclose better reason than elevation to account for glacier radient points —like the Keewatan and Labradorian. The site of the Keewatan radient north of Hudson Bay is reported to be, at this time, almost as flat as the proverbial flounders. The rock strata must have been exceedingly flexible beneath some radient points to have left no marks of their repeated deformations.

Dr. Ortmann affirms that but one mammoth standing erect has ever been found in Siberia and that that one was taken from a bog. Their standing erect is not, however, a very important matter. Reference to the numbers of mammoths so found were based on the positive statement of Lydecker that "many" had

*Author's Closure.

been so disclosed by the casual erosion of river banks and the caving down of the sea cliffs facing the Arctic Sea. Prof. Wright's photograph, to which we refer in the paper, presented the case of one found by the caving of a gravelly sea cliff. So also Nordenskiold refers to the vegetation and soil found beneath the feet of mammoths. From such statements it seemed to be a reasonable assumption that if extensive areas of the tundra was systematically excavated a great many more erect animals might be found. A few years ago the present writer had the gratification of finding a mammoth's tooth in a slight excavation being made in the enormous glacial deposit, 70 to 90 ft. high, and in places (below Beaver on the Ohio River), more than a thousand feet wide, with aggregate length of more than ten miles. The number of teeth and bones possible to be found in such a mass of drift must be left to the reader's imagination.

Dr. Fettke, while on the whole agreeing with Mr. Hice, takes issue with him as to the effect of elevation being all sufficient to develop glacial epochs. There are other geologists who attached more importance to the subsidence of the land to account for glacial phenomena. It surely is a merry scientific war, as the writer has always thought and hence has resulted this appeal to the Engineers—good, natural, unbiased fellows—to step into the field and clear up the situation once and for all.

Mr. Lewis has a good word to say of Dr. Croll's theory in regard to the possible effect of a change in the earth's eccentricity, productive of glaciers. Croll's is purely an astronomical discussion and well worth the study of engineers for delightful "mental recreation." Croll's own declarations are presented quite fully in the Ninth Ed., Brit. Enc., and should be read in connection with remarks in Young's "Practical Astronomy."

SOME ASPECTS OF THE TESTING OF REFRACTORIES[1]

A. V. BLEININGER*

Refractory materials are indispensible in the practice of the metallurgical arts, in the melting of glass, the clinkering of cement, in the ceramic firing process, and last but not least in the generation of steam. According to the temperatures required and the particular conditions of each kind of use, a considerable number of materials is available. The principal types are the clay, silica, magnesite and aluminous refractories. In addition, special refractory materials find more restricted application, such as the carbon materials, carborundum, zirconium oxide and others.

CLAY REFRACTORIES

For the sake of convenience three kinds of clay materials may be recognized in this connection, called for convenience, No. 1, No. 2, and No. 3 refractories. The greatest heat resistance is shown by those clays corresponding most closely to the theoretical kaolinite composition, 46.3 percent silica, 39.8 percent alumina and 13.9 percent chemical water, which upon heating becomes 53.8 percent silica and 46.2 percent alumina, and by the so-called bauxitic clays. The latter are admixed with some bauxite which may raise the alumina content as high as 60 percent (in the hydrous state). The increased amount of alumina brings about a decided increase in the refractoriness of the material. Clay of the purest type possible, kaolinite, has a softening temperature corresponding to the melting point of platinum, 1755°C. or expressed in standard pyrometric cones, to cone No. 35. Owing to the greater or smaller amount of impurities such as silica in the form or quartz, feldspar, lime and magnesia, this softening temperature is hardly ever realized. A softening

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[1] By permission of the Director, Bureau of Standards.

temperature of 1725°C is about as high as is reached by high class fire clays, such as the flint clays. Clays containing bauxite may soften at temperatures as high as 1800°C. A high grade or No. 1 fire clay should not soften below cone No. 31 or approximately 1685°C. This point, therefore, would be about the dividing line between No. 1 and No. 2 fire clays, though others place the limit considerably lower. The division line between the No. 2 and the No. 3 clay refractories would be at cone 28 or roughly 1635°C. Clays softening below this limit might be classed as No. 3 refractories. Although this arbitrary classification may be considered too exacting by some it has worked out quite satisfactorily in a clay testing practice extending over a number of years.

Fire clays may also be divided into two types of clays according to whether they are plastic and dense burning at comparatively low temperatures, say, around 1200°C., or whether they are open burning, i. e., retain their porosity within this temperature region. The clays of the second class are also, as a rule, less plastic than those of the first. The characteristic behavior of the denser burning clays is due, of course, to their higher content of fluxes.

In the temperature-porosity diagram of Fig. 1, clay "*a*" is of the open burning variety while the remainder are of the dense burning class. It happens that this diagram represents five well known European fire clays, of which several have been imported to this country in considerable quantities. In this series clay "*a*" is the famous glass pot clay from Gross Almerode, Germany, clay "*b*" a very plastic crucible clay from Klingenberg, Germany; clay "*c*," a glass pot clay from Kaschkau-Mehren, Germany: clay "*d*" an excellent glass pot clay from St. Loupe, France and clay "e," a plastic fire clay from Breitscheid, Germany.

Silicious fire clays, that is clays with a silica content above 75 percent, possess a lower softening temperature than the highest grade fire clays and are influenced more potently by the presence of fluxes. It is more important that a silicious fire clay be low in the basic constituents, iron oxide, lime, magnesia, potash and soda than an aluminous one since the lowering of the softening point is more marked. On the other hand, silicious

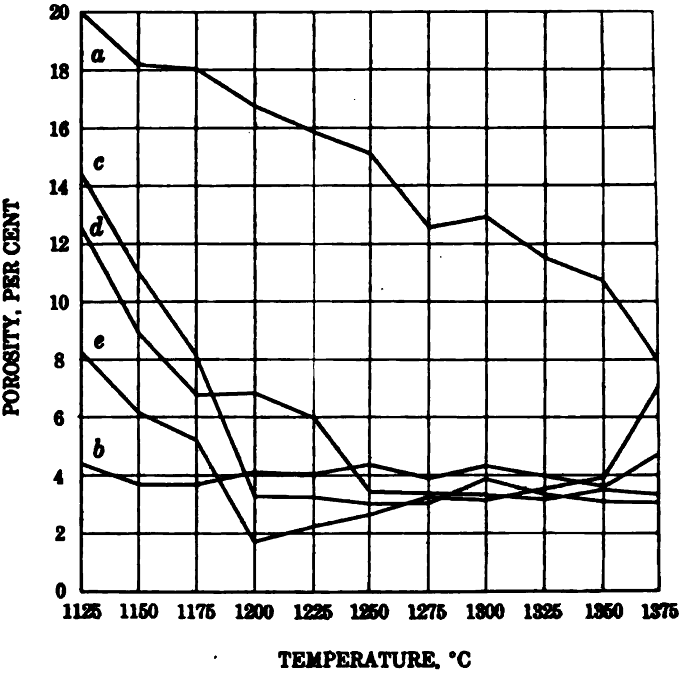

Fig. 1. Diagram Showing Behavior of One Open and Four Dense Burning Clays.

clays have a decided advantage over the average clay fire brick in that they are not subject to shrinkage in use and are able to carry considerable loads at furnace temperatures without showing any appreciable deformation. They are able to stand up well at temperatures not far removed from their ultimate softening point while clay fire brick cannot be safely carried to temperatures within 100°C. below the deformation point. At the same time, clay fire bricks show considerable contraction and soften sufficiently even at temperatures as low as 1400-1450°C. to render them unable to carry loads greater than 10 pounds per square inch. This statement needs to be modified, however, in that high clay fire bricks may be manufactured by the use of highly calcined No. 1 clay (grog) and by high burning of the material so that the contraction is very small and the load carrying power quite high. In doing this the contraction of part of the clay is practically completed in the calcination and in the burning of the bricks so that but a small shrinkage can take place later. At the same time the compact structure is able to resist the usual pressure conditions in furnaces satisfactorily. Such a process of manufacture is expensive. All non-silicious clays tend to shrink in burning, due in part to the colloidal contraction and in part to the effect of the fluxes which are active in lowering the viscosity of the clay, thus bringing about a gradual liquification. In silicious clays this shrinkage is practically eliminated not only on account of the much smaller amount of clay substance present, but also on account of the volume increase of the quartz in its transformation to cristobalite and tridymite. This volume change may be great enough to cause expansion of the brick upon burning rather than contraction. The high silica content, however, brings with it certain disadvantages such as inability to withstand sudden temperature changes which does not apply to clay bricks.

In the manufacture of clay fire bricks two kinds of materials are to be recognized, those made from one, more or less homogeneous clay and those produced from a mixture consisting of a large part of a very refractory hard clay, deficient in plasticity, bonded together by a less refractory but very plastic one which makes possible the molding of the tempered mass. The second case applies to the Pennsylvania fire bricks, in which the ground flint clay is cemented together by a plastic material. It is to be regretted that occasionally the plastic clay is so deficient in refractoriness that it seriously lowers the quality of the product, thus spoiling the effect of the high grade flint clay.

The value of the hard burning of fire bricks needs also be emphasized. There is no doubt but that clay refractories fired to as high a temperature as possible are greatly to be preferred to underburned material, no matter how this may effect the looks of the product. Those who prefer soft burned bricks usually can give no adequate reason for their position.

SILICA REFRACTORIES

These are principally produced from a mixture of ground quartzite and lime paste so that in the fired product the silica content may be from 94 to 97 percent, and that of the lime about

2 percent. The firing of the dried bricks is carried to quite a high temperature usually to above 1500°C. In the burning the lime bond develops to form a mono-calcium silicate and the quartz is transformed to cristobalite, an intermediate crystalline modification of silica. It has been shown by Kenneth Seaver[1] that in industrial practice the transformation of the quartz to cristobalite is practically as complete as is possible. This transformation is coincident with the expansion of the brick, usually three-eighths inch to seven-sixteenths inch per linear foot over the mold measurements.

This linear expansion may be used as the criterion of the proper degree of burning though it is by no means completed in the kiln but continues upon heating the bricks in use. The cristobalite, constituting about 80 percent of the finished silica brick, is not the stable phase at the temperatures involved but is further transformed to tridymite. Smaller quantities of this crystalline modification of silica are usually found in silica brick and some time after the latter are in use, provided the temperature is sufficiently high, it becomes the predominating constituent. Thus in open hearth or glass furnaces the silica brick structure consists mainly of tridymite. The proposal of Grzimails[2] that silica bricks be fired in kilns until the tridymite transformation is completed would make the cost of manufacture prohibitive. It might perhaps be possible to bring about the desired transformation by the use of catalyzing agents such as small quantities of borate of lime but this subject has not yet been investigated. Unless, however, most of the quartz has been transformed to cristobalite a silica brick is deficient in quality.

Although the refractoriness of silica refractories is lower than that of the high grade clay bricks, corresponding to about 1700°C. their effective, useful temperature range is very extensive. Their rigidity and freedom from deformation at high temperatures, say 1600°C. is superior to that of clay refractories. Failure as a rule occurs quickly near the softening temperature and there is no long interval during which serious deformation may occur. Vesicular structure, such a prominent difficulty with many refractories molded in the plastic state is practically absent.

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[1] Bulletin American Inst. Mining Eng., 1915.

[2] Stahl and Eisen, 1911, No. 6.

The one difficulty associated with the use of silica brick is their inability to stand up well under conditions of sudden heating and cooling. When subjected to such treatment they tend to spall and break down, especially if cooled below 600°C. Silica bricks are made also in which clay is introduced as a bond in place of the lime. This class of ware resembles the silicious fire clays in behavior. As a rule they are not quite as satisfactory as the lime bonded materials though they are somewhat more resistant to sudden temperature changes. Silica in the form of diatomaceous earth, kieselgur, admixed with clay and sometimes with cork dust, etc., is also made into a type of refractory possessing remarkable heat insulating quality. In this case refractoriness is secondary to this thermal property.

ALUMINOUS REFRACTORIES

The use of bauxite and mixtures of bauxite and fire clay is assuming larger proportions than it has in the past. This is particularly true at the present time when due to the scarcity of magnesite, a substitute for the latter is being sought. From accounts which have been obtained it seems that it is possible to use refractories of this type successfully for purposes where magnesite seemed indispensible. The hydrous bauxite ores usually are impure, containing as a rule, 5-6 or more percent of ferric oxide. This applies to most American bauxites. The melting point of pure alumina is about 2049°C. but that of bauxite does not as a rule exceed 1820°C. A very high shrinkage upon heating is characteristic of bauxites and hence it is important that as large a part of the material as possible be previously calcined. Unless this is done and the calcination carried to a high temperature the shrinkage of the product in use will be so high as to render it very unsatisfactory. Bauxite tends to contract also under pressure at furnace temperatures and hence is not so well adapted for uses where severe load conditions prevail. Owing to the feebly plastic nature of bauxite, bricks consisting of calcined and raw bauxite are rarely made. Usually a good fire clay is employed to bond together the calcined bauxite. This naturally reduces the refractoriness of the mixture so that bauxite-clay fire bricks do not, as a rule, possess a softening temperature above 1800°C. Bricks of this type are sold on the basis of the alumina content.

Greater refractoriness can of course be reached by the use of refined bauxite from which a large part of the iron oxide has been eliminated by chemical treatment.

Alumina is also an important constituent of refractory porcelain such as is used for pyrometer tubes, the so-called Marquardt porcelain. Here a considerable amount of alumina, previously calcined together with some feldspar is introduced as the non-plastic portion of the mixture which in addition contains more feldspar and plastic kaolin. The fact might be mentioned that Marquardt porcelain of excellent quality has been produced by the Pittsburgh laboratory of the Bureau of Standards, covered both with a bright and a matt glaze.

MAGNESIA REFRACTORIES

The magnesite products represent typical basic refractories. Two kinds of magnesite are to be distinguished, rocks approaching pure magnesite in composition such as the Grecian and California materials and the impure ones, containing from 3 to 8 percent ferric oxide and more or less silica, of which the Austrian magnesite is characteristic. The melting point of pure magnesia is very high, about 2800°C. but that of magnesite brick rarely exceeds 2170°C. Owing to the extreme heat resistance of the material and its great shrinkage, about 50 percent, by volume, pure magnesite is not suitable for refractory purposes since it would be exceedingly difficult to reduce it to practically constant volume, while owing to the fluxing action of the ferric oxide in the impure material the latter is more easily compacted.

The calcination of the magnesite is very important and in Europe it is conducted in shaft kilns working with forced draft. Rotary kilns would be well suited for this purpose. The dead burned magnesite, after having been crushed is then intimately mixed with some low burned magnesite, moistened with water and shaped into bricks under considerable pressure. The soft burned magnesite functions as the cementing material. The bricks are then dried and burned in kilns to a high temperature. Magnesite bricks, owing to their basic nature and high heat resisting quality form a valuable refractory. Magnesite is subject to certain limitations however in use, such as its tendency to spall when subjected to sudden temperature changes and its friable character under conditions of abrasion. The shortage of magnesite due to the European war conditions has made it necessary to look about for substitutes. In many cases bauxite materials have been found very satisfactory indeed and it has been reported from several sources that this material has been permanently adopted. Dolomite has also been used as a substitute. For this purpose impure dolomite can only be used as it is necessary to "dead burn" the material as much as possible before attempting to make it either into bricks or to tamp furnace bottoms with it. A fairly high content of iron oxide is to be preferred as in the case of magnesite and the calcination temperature should be carried as high as possible. Attempts have been made also to coat the crushed dolomite with a pulverized slag suspension in water so that upon burning a protective coating would be formed on the surface. Unfortunately in several such cases the slag was decidedly basic and hence did not enter into intimate combination with the dolomite. A more acid slag would certainly be preferable for this purpose. The calcined dolomite, crushed to the desired fineness is then mixed with hot tar as soon as possible and molded into bricks. These then must be burned again in order to remove the tar and bring about some consolidation of the particles. For tamping the tar likewise is used as the bonding material. Dolomite materials of this sort are invariably apt to slake upon standing in the air. In spite of this difficulty it has been used to a considerable extent in European practice for many years.

CARBON REFRACTORIES

Probably the best known application of carbon for refractory purposes is in graphite crucibles, nozzles, etc. In these from 40 to 60 percent of graphite is introduced. A small amount of calcined clay (grog) is also used and the whole bonded together by means of a very plastic fire clay. The graphite comes from Ceylon and the bond clay generally employed for this purpose has been the Klingenberg clay, imported from Germany previous to the war. Difficulty is being experienced at the present time in securing the graphite and the importation of German clay is, of course, completely cut off. The supply of domestic graphite appears to be inadequate and its quality is said to be inferior to that from Ceylon. A shortage in graphite would make it necessary to resort to the use of artificial graphite, carborundum, gas carbon, electrode carbon or even ground coke. Coke bricks and similar refractories have been used in Europe for many years and the use of this material might be extended to crucibles even though their life would be considerably shorter than that of the graphite products.

The elimination of the German bond clay is not a really serious matter as it is quite possible to obtain similar results, not by the use of any single American clay but by a mixture of two plastic fire clays, one of which is of the dense the other of the open burning variety. By correct proportioning, the requirements of both brass and the steel melting should be satisfied. Such clays can be found among the so-called ball clays of Kentucky and Tennessee and the plastic fire clays of Pennsylvania, Missouri and Ohio.

For certain purposes carborundum-clay mixtures have been used but apparently with indifferent success.

MISCELLANEOUS REFRACTORIES

Among the rarer and more costly refractories chromite is to be mentioned, employed as a neutral parting between acid and basic refractories. The melting point of the chrome product has been found by Kanolt to be near 2180°C.

Pure magnesia fused in the electric furnace is sometimes used as a refractory for small installations, but its use becomes prohibitive in larger quantities due to the high cost of preparation. Refractory mixtures of this type are made up with as much as possible of the fused and a small amount of low burned or plastic magnesia which functions as a binder. Sometimes a small amount of magnesium chloride may be used to assist in cementing together the fused or sintered particles by virtue of a Sorel cement reaction. Crucibles of pure, fused magnesia have been made in Europe for some time and have been found useful for many purposes. The melting point of pure magnesia has been estimated by Kanolt to be 2800°C.

Fused, pure alumina has been used extensively in the manufacture of small crucibles, tubes, furnace linings, cores for winding resistance heating wires, etc. Its melting point is approximately 2050°C. (Kanolt). Although admirably adapted to many uses it has certain limitations such as its permeability to gases and the long temperature range below the melting point during which it tends to soften and deform.

One of the rarer, though promising refractories is zirconium oxide, obtained from the Brazilian zircon earth which carries as high as 90 percent of the oxide, about 4 percent of ferric oxide and 6 and more percent of silica. Refractories have been made from this material, the bulk of which consists of the ZrO_2, previously fired to a high temperature, and zirconium hydroxide as a binder which may be supplemented by the use of starch. Such refractories have been found to show no sign of fusion at 2200°C. to be indifferent to temperature changes and to possess high di-electric strength even at high temperatures.

For certain purposes magnesia spinel may be found to be a useful refractory. It corresponds to the formula $MgO.Al_2O_3$ and is prepared by heating to a high temperature a thoroughly blended mixture of 102 parts alumina and 40 of magnesium oxide. Although this compound does not possess a very high melting point it is useful for certain purposes owing to its inertness to dissolving agencies and the absence of any tendency to corrode platinum or other metallic wires. It has been found a useful refractory in several metallurgical researches.

Boron nitride is a rarely used refractory and comparatively little is known concerning its behavior for the purposes under discussion here.

THE TESTING OF REFRACTORIES

Melting Point: One of the fundamental properties of refractories is a melting or softening point sufficiently high that rigidity of the material is maintained under the temperature conditions involved. Comparatively few of the refractories possess a melting point in the proper sense of the word. Most of them show more or less a certain degree of softening during a given temperature range which may extend throughout several hundred degrees. Thus the rigidity of the substances decreases gradually and at the so-called softening point the viscosity has been diminished to such an extent that deformation takes place under the action of gravity. By molding test specimens in the form of small tetrahedra, corresponding to the shape of the well known pyrometric cones, a condition of softening is established which may serve for purposes of comparison. When the cone bends so that its apex touches the supporting plaque it is said to have gone down or "melted." The temperature at which this takes place is by no means a constant but varies generally with the size and shape of the cone, the fineness of grinding of the material, the rate of heating and in the case of ferruginous materials, with the condition of the atmosphere, i. e., whether reducing or oxidizing. Many basic mixtures made up in the form of cones do not deform in the manner described but fuse into a round ball or drop. Such behavior is indicative of a real melting point. Owing to the fluctuations in the arbitrary softening point mentioned above it is a misleading practice to speak of the melting point of clays and similar materials. It has been pointed out time and again that the standard Seger cones can be caused to deform at higher or lower temperatures according to whether they are heated rapidly or slowly. It is not uncommon to find, for instance, that such a cone may go down anywhere from 50 to 100°C. below the temperature given in the tables by being heated slowly in a commercial furnace or kiln. It would be desirable therefore either to depend upon pyrometric measurements in connection with a definite rate of heating or to establish the real values of the cone softening points under the conditions of use by standardizing with the aid of a good pyrometer. It would be far better to state simply the number of the cone which has gone down under certain conditions than to make use of the "official" temperature given for the same number.

At the present time, electric carbon resistance furnaces are used most frequently for the determination of the softening points of refractories. In the case of refractories quite high in iron oxide erroneous results are obtained in such a furnace due to the reducing action of the carbon monoxide. In vacuum furnaces of this type or by the use of a current of inert gas through the tube containing the specimens this difficulty may be diminished.

Again, by employing molybdenum or tungsten wire electric furnaces and maintaining constant conditions by causing a mixture of hydrogen and steam to flow through the tube, according to the procedure of Fieldner and Hall of the U. S. Bureau of Mines[3] very satisfactory results can be obtained. It might be stated however, that such furnaces require skilled attendance and are limited as to the maximum temperature which may be reached. For temperatures, up to about cone 32, satisfactory comparative results may be obtained by using a simple pot furnace, heated by means of a gas blast burner and by preheating the air used for combustion. The softening temperature of refractories may be determined by means of optical pyrometers, such as the Holborn-Kurlbaum or the Wanner or it may be estimated by means of the standard pyrometric cones.

Constancy of Volume: Changes in volume due to the shrinkage or expansion of a refractory in use are obviously of considerable practical importance. Such changes are also indicative of the quality of the material. Thus a fire brick which shows a marked shrinkage in use is inferior in quality to a material which shows only a small change in volume. Excessive shrinkage of clay fire bricks is due either to insufficient firing or to inferior quality of the raw materials. Contrary to the opinion of some it is true that the harder a fire brick is burned the more satisfactory it is for most purposes.

Excessive shrinkage may be caused by the inferior refractory quality of the bricks so that upon heating them to higher temperatures more or less pronounced vitrification takes place accompanied by reduction of the pore space and general contraction. The contraction or decrease in porosity of a fire brick at different temperatures may thus be considered a valuable criterion of its quality and when plotted in the form of a curve and data enables us to judge the material quite accurately as to its refractory value, In fact such information could serve as the basis of a

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[3] The Fusibility of Coal Ash, Proc. Am. Soc. Testing Materials, Vol. XV, p. 297.

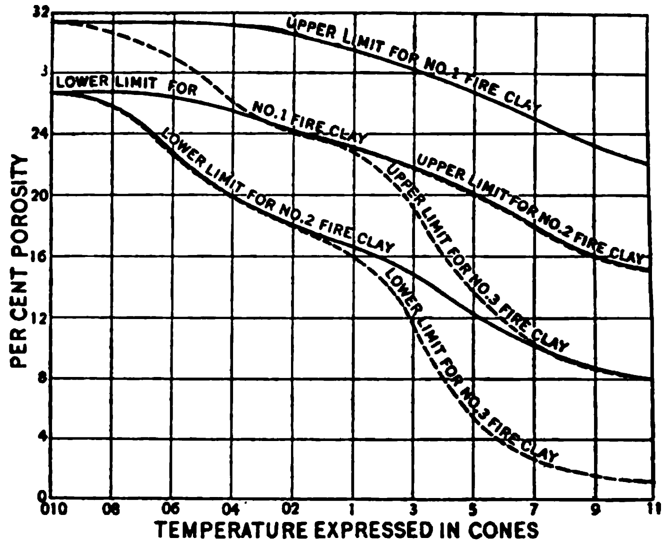

Fig. 2. The Classification Diagram of Fire Clay, by Purdy.

classification of fire clays, as has been suggested by R. C. Purdy[4], who proposed the diagram of Fig. 2 for this purpose. Although the limits given by him do not agree with the facts known concerning fire clays at the present time his method of arriving at a basis of comparison for the grading of the various fire clays is thoroughly sound. A study along this line in connection with the best known fire bricks of the United States is now being carried on by the Bureau of Standards. Based on similar reasoning it has been proposed to test fire bricks by re-heating them to several temperatures according to their grade and determining their linear contraction. Thus it has been suggested that No. 1 clay fire bricks should be heated to cone 14 (about 2570°F.) and should show a linear contraction of not more than 2 percent. Similarly No. 2 fire bricks should not contract more than 2 percent at cone 12 (2462°F.) and No. 3 materials 2 percent at cone 8 (2282°F.). English specifications for gas refractories require that the No. 1 grade shall not contract or expand more than 0.75 percent, heated to cone 12 for two hours and the No. 2 grade not more than 1 percent under the same conditions.

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[4] Ill. State Geol. Survey, Bull. 9, p. 221.

Fire bricks undergo also volume changes connected with deep seated molecular changes such as the dissociation of the clay substance into sillimanite at high temperatures. The well known decrease in crushing strength suffered by clay refractories upon long heating has been shown by Mellor[5] to be due in part to the growth of crystalline structure. Zoellner[6], in fact, was able to separate from high grade fire clays burned to a temperature corresponding to cone 15, from 2 to 22 percent of sillimanite by treatment with dilute hydrofluoric acid. However the apparent volume changes accompanying these phenomena are slight compared with the contraction due to progressive vitrification.

In silica brick excessive expansion upon reheating is usually due to incomplete transformation of the quartz to cristobalite, a consequence of underburning. Some specifications like those of the American Gas Institute are very stringent with reference to this point and require that upon reheating to 1500°C. (2732°F.) the permanent linear expansion shall not exceed 1 percent. In the case of bauxite or magnesite bricks excessive contraction is likewise due to insufficient burning.

Resistance to Load Conditions: It has already been stated that with increasing temperature the viscosity of refractories decreases. The greater the amount of fluxes present the more marked is this degree of softening. It has been suggested therefore that the deformation at certain temperatures and under given loads be used as a criterion of the refractoriness of fire bricks. Recent work by the Bureau of Standards[7] on the contraction of fire bricks when reheated to 1300° and 1350°C. under different loads has given the results shown in Table I:

It follows from these results that the softening of the bricks becomes clearly manifest at 1350°C. which seems to be the more suitable temperature for this test. The load to be employed should not be greater than 40 pounds per square inch and not less than 25 pounds. The requirement as regards deformation must necessarily vary according to the particular use of the bricks. For gas works refractories it has been proposed to specify for grade *"A"* clay fire brick a linear shrinkage not exceeding 2.5 percent, the test being conducted at 1350°C. and with a load of 25 pounds per square inch. These specifications are exacting and can be met only by well burned fire bricks of excellent refractoriness. The above results are in line with those obtained by Mellor[8] in which he found that the deformation temperature of fire clays is reduced the more the greater the pressure. The same investigator found the relation between the deformation temperature *"T"* and the load *"W,"* expressed in pounds per square inch to be expressed by the equation,

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[5] Pottery Gazette, 1907, No. 367.

[6] Dissert, Aachen, 1907.

[7] Report of the Committee on Refractory Materials, American Gas Institute, 1915. Technologic Paper No. 7, Bureau of Standards.

TABLE I.

No. of Specimen.	Load, per sq. inch.	Contraction in per cent. of length.	
		at 1300°C	at 1350°C
1	50	1.06	....
1	40	1.06	3.46
1	25	0.35	2.48
1	15	....	1.03
1	0	0	0
2	50	2.17	....
2	40	2.17	3.26
2	25	0.72	1.81
2	15	....	1.45
2	0	0	0
3	50	3.83	....
3	40	3.11	4.82
3	25	1.73	3.50
3	15	....	3.44
3	0	0	10.07
4	50	1.03	....
4	40	0.70	3.86
4	25	0	2.41
4	15	....	1.41
4	0	0	0
5	50	1.80	....
5	40	1.08	3.26
5	25	1.08	2.89
5	15	....	1.08
5	0	....	...

$$T = Ce^{-KW}$$

where

C = deformation temperature of specimen without load.

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[8] Trans. Engl. Ceramic Soc., Vol. XV, part I, p. 117.

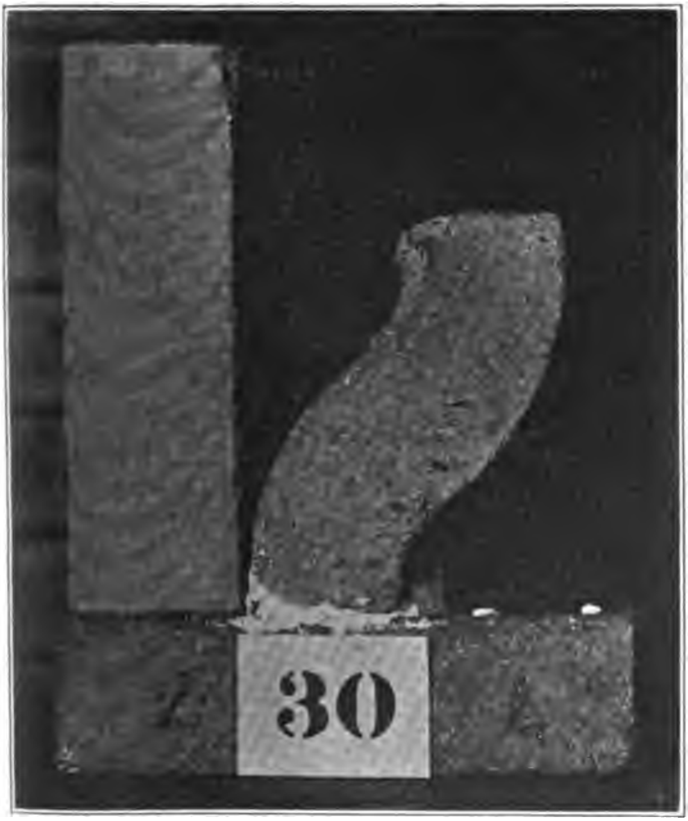

Fig. 3. Failure of Fire Brick in Load Test Due to Deficiency in Refractoriness.

K = a constant, the numerical value of which depends upon the particular clay, mode of fabrication, etc.

e = exponential constant.

The temperature may be expressed in degrees centigrade or in terms of Seger cones. The more silicious the clay, the less the difference between the deformation temperatures with or without load. On the other hand the more the composition of a material approaches that of the pure clay substance the greater is the difference between the deformation temperatures with and without load. The "squatting" temperature of china clay is low-

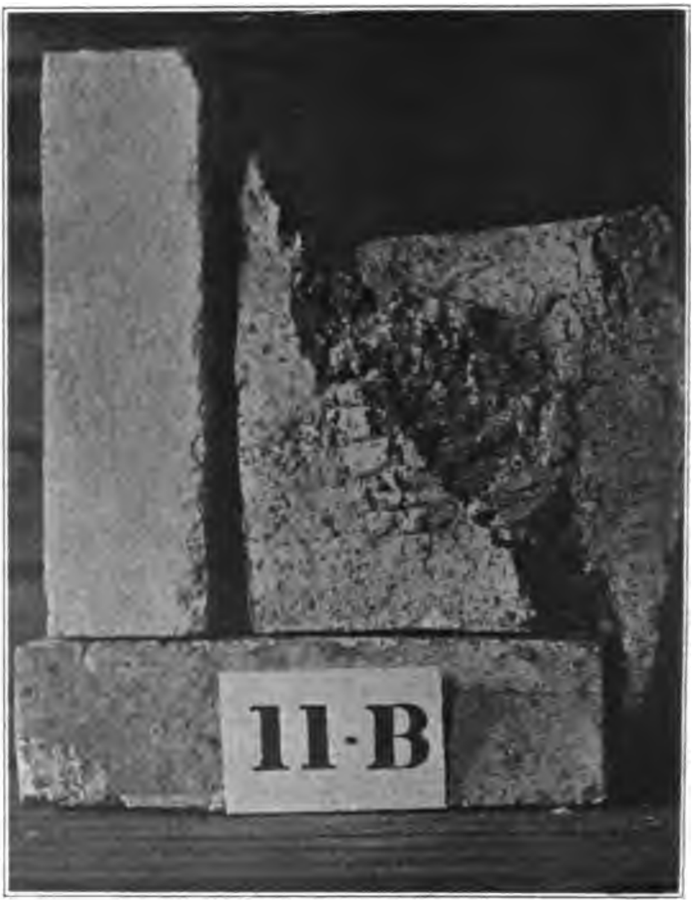

Fig. 4. Failure of Fire Brick in Load Test Due to Deficiency in Refractoriness and Poor Bonding.

ered approximately one cone for every increase of 5¼ pounds per square inch in load.

Silicious clay fire brick and silica bricks are best suited to withstand pressures at furnace temperatures inasmuch as they expand rather than contract and suffer practically no deformation. As far as silicious clays are concerned this holds only for materials low in fluxes. Clays of this type, high in iron oxide and other fluxes may show decided and sudden contraction at temperatures of about 1350°C.

The structure and density of fire bricks have some influence upon the resistance to load conditions. In flint clay fire brick the proper bonding of the grains is important. Hard burned bricks stand up better than soft fired material.

The photographs of Figs. 3 and 4 illustrate two types of failures. The one of Fig. 3 is entirely due to deficient refractoriness of the material, that of Fig. 4 to both low refractoriness and poor bonding of the grains.

It is possible however to produce high clay fire brick showing excellent resistance to load conditions by using a mixture containing as high a percentage as possible of calcined No. 1 fire clay and a very refractory bond clay. Such bricks have been made under the direction of the writer and were found to possess an exceedingly small contraction with a load of 50 pounds per square inch and at temperatures of 1350-1400°C.

Silica brick are the material most resistant to load conditions in furnaces though unfortunately they are subject to difficulties in resisting sudden temperature changes. Silica brick under a pressure of 50 pounds per square inch stand up at temperatures as high as 1500°C. Bauxite bricks unless exceedingly well burned are apt to show decided contraction. Magnesite bricks stand up well at temperatures as high as 1550°C. when they are liable to break down suddenly under loads of about 50 pounds per square inch. Chrome brick resist this load up to temperatures of about 1450°C, when like the magnesite brick they are apt to fail suddenly.

Resistance to Sudden Temperature Changes: The quality of refractories to resist sudden heating and cooling is an important one and tests dealing with this qualification have been made for a long time by builders of coke ovens and erecting engineers specializing in steam boiler installations. The most common mode of testing consists in heating the fire bricks to a red heat and then dropping them in cold water. The number of such quenchings withstood by the bricks is considered a criterion of their value in this connection. Others heat the bricks to a certain temperature, say 1000°C, and upon removal from the furnace cool them in the air by placing them on an iron plate, which may or may not be cooled by contact with running water. Again others heat the specimens to red heat, remove them and cool them on one side by means of a cold blast of air. It is thus seen that no uniform methods exist and that hence reliable comparisons are not available.

Resistance to Slagging Action: In many metallurgical operations the resistance of the refractories to the corrosive action of the slag or in the glass industry to the action of the fusing glass is a factor of considerable importance. The penetration of slag into the bricks is obviously greatest where there is a well developed capillary system of pores and least where the structure is densest. At the same time the nature of the exposed surface is not to be neglected since it has been found that certain vitrifying cements applied to the surface and, of course, penetrating into the structure to some extent are quite efficient in causing the refractory to resist corrosive slag action. While, of course, the selection of the slag or glass must depend on the particular conditions to be met, no uniformity exists as to the procedure of the tests. Some cause the slag to act upon the surface of the specimens at a suitable temperature, others drill a hole into the material to be filled with a given quantity of slag and some partially immerse the bricks in a bath of slag contained in an appropriate receptacle. Figures 5 and 6 illustrate the last type of test and show slag infiltration in one case and resistance to this action in the other. The writer is indebted to Mr. G. H. Brown, of the Bureau of Standards for these photographs.

Thermal Properties: Several of the thermal properties of refractory materials are of considerable practical interest. It must be realized however, in this connection that none of these properties are constant throughout the range of furnace temperatures. Like all physical constants they vary with temperature and in addition with the mode of manufacture, and such structural changes which are inevitable where refractories are heated for a long time. For instance, the coefficient of expansion of a clay fire brick, determined say between 0 and 100°C. does not hold for higher temperatures. The same is true of thermal conductivity, specific heat and other properties. The mean coefficient of expansion of fire brick is usually estimated to be 0.0000097, (referred to 1°C).

Boeck[9] has found the coeffiecient for a plastic fire clay, burned to cone 12, to vary as follows:

	First run	Second run
Between 24° to 100°C	1316×10^{-8}	1310×10^{-8}
" 100° to 200°C	1710×10^{-8}	1610×10^{-8}
" 200° to 700°C	558×10^{-8}	580×10^{-8}
" 200° to 900°C		567×10^{-8}

The specific heat of refractories has not yet been determined satisfactorily for a number of such substances. For clay fire brick this relation has been expressed by Mellor[10] by the equation:

$$S = 0.193 + 0.00006t$$

where

S = specific heat.

t = temperature, in degrees centigrade.

The thermal conductivity of the materials under discussion is a direct function of the porosity. Thus a dense brick showed at 1400°F. a heat flow of 124 B. t. u. through one square foot area, one inch thick, per 24 hours, for a temperature difference of 1°F. A somewhat more porous brick, under the same conditions conducted 87 and a "kieselgur" brick, extremely porous, 22 B. t. u.

The variation of the thermal conductivity of fire bricks with temperature and reheating is illustrated by the work of Heyn[11] which is compiled in Table II. Here the value of K represents the heat flow in calories per second through 1 square cm. and 1 cm. thickness, per 1°C, temperature difference. The figures are of the order, $K = 0.001 = 100$.

TABLE II.

	K at the temperatures, °C.						
Kind of fire-brick	200	400	600	800	1000	1100	1200
High Clay	145	180	220	240	260	270	....
More Silicious	115	140	165	190	215	...	....
Silicious	90	110	125	130	130	...	....
Silicious	210	245	270	270	270	270	270
Silica Brick	135	160	170	170	180	210	240
Magnesite	110	115	120	130	140	140	...

[9] Trans. Am. Ceramic Soc., Vol. XIV, p. 470.

[10] Trans. English Ceramic Soc., Vol. XII, part I, p. 279.

[11] Stahl and Eisen, Vol. XXXIV, p. 832.

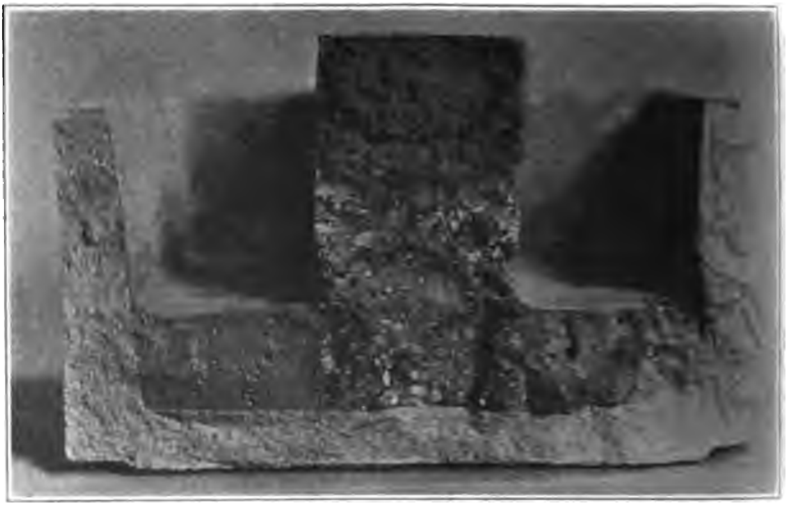

Fig. 5. Fire Brick Showing Penetration by Slag.

According to the well known results of Wologdine the absolute thermal conductivity coefficients (gram calories per second, through 1 square cm. area and 1 cm. thickness, for 1°C. temperature difference) have been found as given in Table III.

TABLE III.

Substance.	Thermal Conductivity.	Porosity, % by Volume
Fire brick	0.0030 — 0.0042	24–30
Bauxite	0.0031	41.5
Silica	0.0020 — 0.0031	42.0
Magnesia (1300°C)	0.0065	41.0
Grecian magnesite	0.0071	31.5
Carborundum (1300°C)	0.0145	30.6
Graphite (1300°C)	0.0185	28.4
Chromite	0.0047 — 0.0069	21.3
Kieselgur	0.0018	58.0
Porcelain	0.0046	....

The values obtained for silica do not seem to correspond with the facts as they are known concerning commercial silica brick which have repeatedly been found to be better heat conductors than clay refractories. Our general knowledge concerning the thermal qualities of refractories is still decidedly deficient and is in need of much further work.

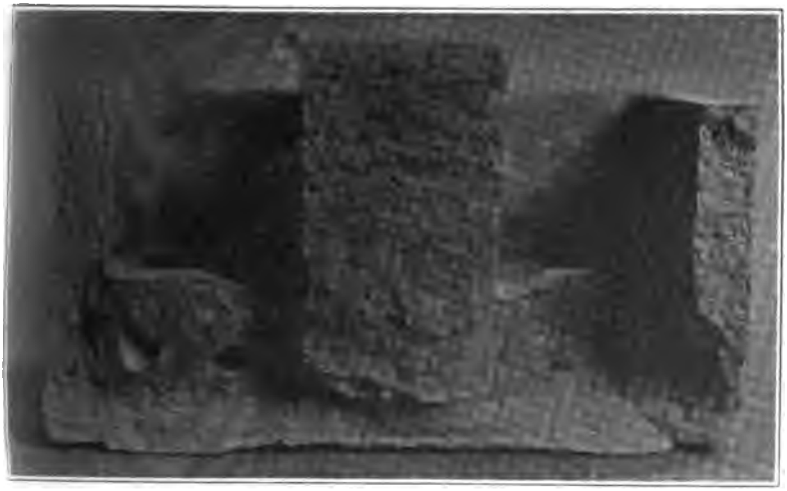

Fig. 6. Fire Brick Resisting Penetration of Slag.

Chemical Composition: Knowledge of the chemical composition is necessarily of fundamental importance in explaining the behavior of refractories. It is questionable however, whether analysis is necessary for general testing purposes unless demanded in cases where the material is of doubtful quality. Such physical tests as the determination of the softening point, the porosity drop of refractories upon reheating, the load test, etc., in themselves integrate the sum of the qualities which depend upon the chemical composition. It would seem then that chemical analysis would be restricted to establishing the limits of composition for classes of refractories, for establishing the superiority or inferiority of a certain material or explaining the causes of failure. For routine testing it does not appear to be essential. It has been possible to make generalizations, for instance, concerning clay fire brick, intended to withstand severe load conditions at temperatures of about 1350° and it was found that the total RO content (ferrous oxide, lime, magnesia, potash and soda) should not exceed 0.22 molecular equivalents. This value is calculated in a very simple manner from the chemical analysis and expresses the amount of total fluxes. By means of the same computation the molecular equivalents of silica are likewise obtained, that of alumina being equal to unity in all cases. Owing to the tedious nature and difficulties of silicate analysis it is evident that physical tests, the results of which are available in a short time, are preferable to chemical determinations.

MORTARS AND CEMENT

In using refractories the quality of the mortar used is of great importance. In each case the mortar should approach very closely the composition and grade of the refractory. Highly refractory materials should be laid up with mortar of corresponding quality and with joints as thin as possible. The use, for instance, of a low grade fire clay in connection with high grade fire bricks is bound to be injurious. Attention might be called also to the use of special mortars and cements for such purposes as securing impervious joints and protecting refractories from the infiltration of gases or corrosion of slags. Where, for instance, units are to be united to form a compact structure, porcelain cements containing feldspar or other non-corrosive fluxes may be very valuable. Again by coating brick work with a cheap refractory glaze of the porcelain type impermeability to gases may be secured. By the use of a suitable silicate flux of the desired acidity, it may also be possible to protect refractory surfaces from corrosion by slags or glass.

DISCUSSION

CHAIRMAN A. N. DIEHL[*]: I am sure we appreciate the very excellent paper prepared by Dr. Bleininger. The paper demonstrates that a lot of work has been done in the right direction The subject of refractories, in my mind, has not yet received the specific investigation, which its importance demands. In the last few years, investigations have become quite general, leading principally to the practical testing of refractories rather than a mere chemical analysis, which is of questionable value. The practical testing has been advancing in wonderful strides, and there is no more urgent time for this work to be done, than during the present condition of restricted refractory supply and the unusual demand for refractory quality. The subject is now open for discussion, and it is hoped that many recommendations for the improvement of the ceramic art will be advanced.

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[*] Asst. Gen. Supt., Duquesne Works, Carnegie Steel Co., Duquesne, Pa.

MR. JAMES O. HANDY†: Every one must feel that the subject has been so well covered by Prof. Bleininger that there is very little left to ask about. One question regarding silica brick with lime bond. Does it make any difference in the properties of the resulting brick whether the bond is relatively pure lime or whether it is a dolomitic lime? Have any experiments been made with magnesia as the bond?

Concerning the durability of the dolomite brick made from impure dolomite with the use of tar as a temporary for the dolomite, is there sufficient fusible impurity present to make them durable or must they be protected from the atmosphere in order to retain their shape and strength.

MR. A. V. BLEININGER: It has been found that high calcium lime is to be preferred. The dolomite lime is not a satisfactory bond. It seems that this conclusion has been arrived at on very good evidence. As to the dolomite bricks, I would like to say that the slaking tendency is quite marked with all kinds. If the dolomite bricks are to show reasonable resistance to slaking, the material must be quite high in fluxes in order that the particles may be slagged together to produce the necessary bond. Still the slaking tendency of dolomite brick is much more marked than that of magnesite, even though they have been burned to a high temperature.

MR. C. E. NESBITT*: In the past two or three years we have been trying to develop a series of tests that will tell us something of the physical properties that are met with in service conditions. I have a few slides here that illustrate some of our work, and I might say, while we are largely interested in the refractory bricks as used around iron and steel works, our methods, with slight

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*Chief Chemist, Edgar Thomson Works, Carnegie Steel Co., Braddock, Pa.

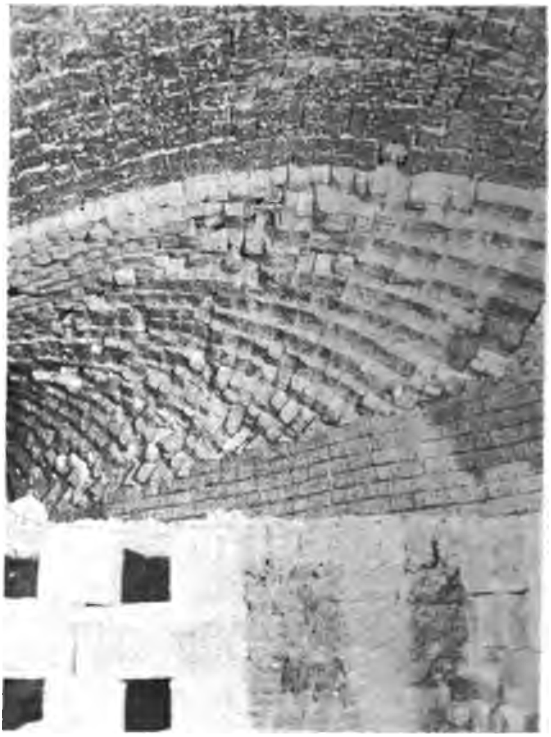

Fig. 7.

modifications, are applicable to any industry where similar service conditions occur.

We place very little importance on the softening point test, as our load test tells the same story in a better way. We run the softening test, however, by sawing off a corner of the brick, making a cone 3-inches high with 1-inch triangular base. We then mount this cone with a number of Seger cones on some refractory material and heat gradually until signs of softening are noted, such as bending, bloating, etc.

Figure 7 illustrates the spalling in the roof of an open-hearth flue. Note the appearance of these brick that have spalled. Now note the similarity between Figure 8, our spalling test, and the bricks that were spalled in service in the preceding slide. In our spalling test we place the brick to be tested in the door of our

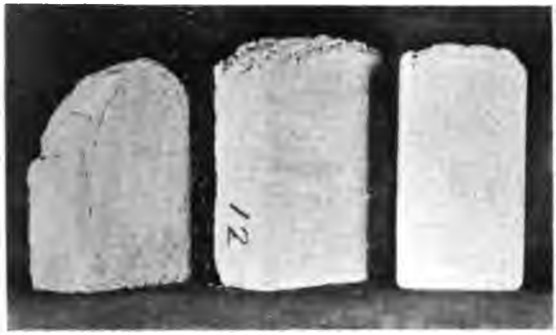

Fig. 8.

kiln, so that the inner surface is flush with the inside of the kiln. We heat up to 1350°C. for one hour and then plunge into 4-inches of water for three minutes. Repeat ten times. The percent loss in weight of the dried brick is reported as spalling value. Note the peculiar spall of this brick owing to its manufacture.

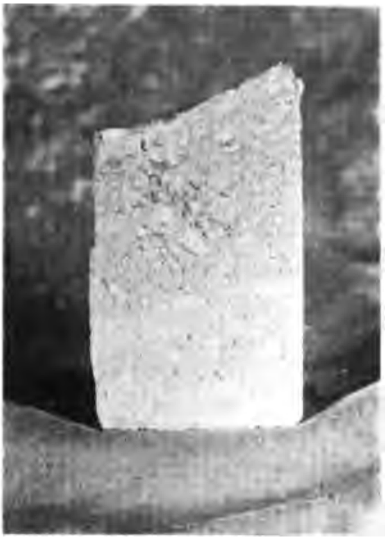

Fig. 9.

Figure 9 illustrates slag penetration under service condition. Figure 10 represents our slag test. Note the similarity to service

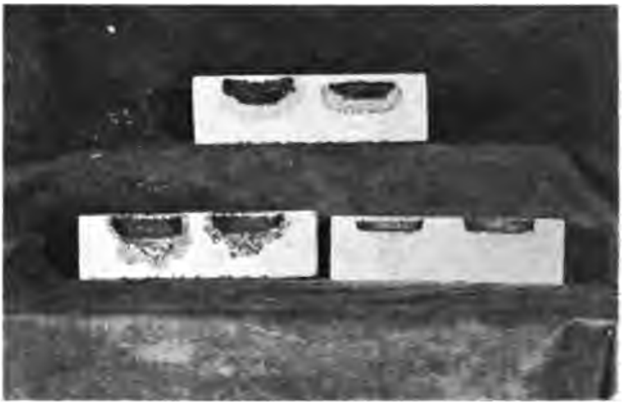

Fig. 10.

brick. We drill standard size cavities in the brick, heat gradually to 1350°C., place a standard amount of slag in the cavity and hold at this temperature for one hour. When cool the brick is sawed through the center and the area of slag penetration exposed determined by means of a planimeter.

Figure 11 shows the results of a slag test in which the brick was placed in a tray of slag and held at 1350° for one hour. The brick when cold was then broken at right angles to its length. These two sections were 1¼ and 2½ inches, respectively, from the fracture section. Note the big variation in slag penetration from 1.6 square inches to 5.5 square inches.

Figure 12 shows the corner of an open-hearth flue breaking and sagging under the effect of load at high temperature. Figure 13 illustrates our load test apparatus, which is nothing more than a modified Brinnell test applied to a brick heated to 1350°C. for one hour. Figure 14 gives a good idea of a brick which nearly fails under our load test, and the other brick which stands up well under the test. The depression in the brick made by the ball is measured by a depth gauge and the results reported in inches. I might state at this point that we checked up our method against Mr. A. V. Bleininger's method and were agreeably surprised to find that the results were identical. One advantage our test has is that we can run 15 while he is running one.

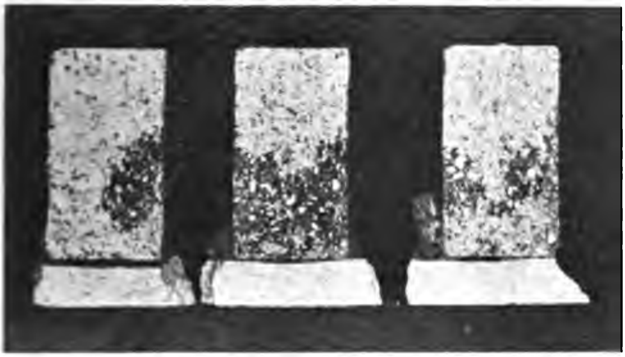

Fig. 11.

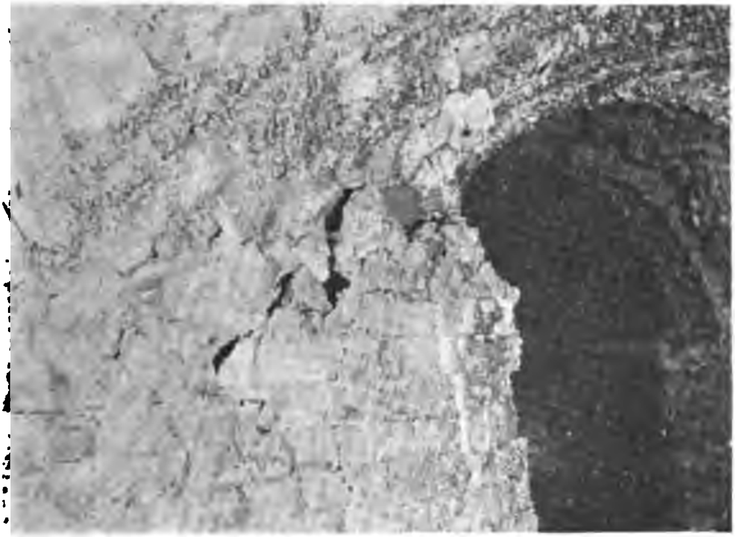

Fig. 12.

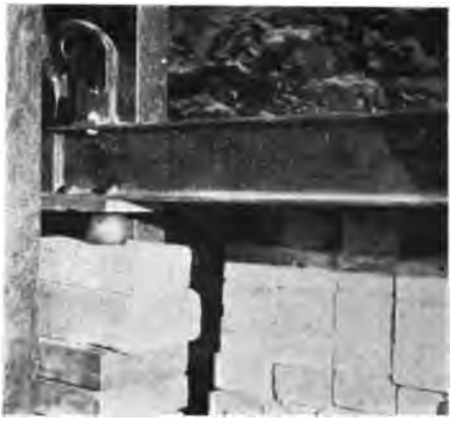

Fig. 13.

We use a micrometer for measuring bricks in determining size, expansion or contraction.

MR. R. H. H. PIERCE*: I do not know that I have anything to add either to Mr. Bleininger's paper or what Mr. Nesbit has given us, as I did not expect to enter into this discussion. Mr. Bleininger has certainly covered the subject in an admirable way. Mr. Nesbit has given us a little work strictly from the practical standpoint, whereas Mr. Bleininger has considered it in his paper chiefly from the experimental side.

This question of slag penetration is a very important one, and as has been shown by the slides, the brick may fail, not due to the slag having any definite chemical action on the particles of the brick, but simply by the slag being absorbed, and in its molten condition washing away the portions of the brick. You may have noticed in some of the slides that the particles of flint clay, or in case of the silica brick the particles of ganister, stand out very prominently in this slag mass, showing that the slag has merely worked into the pores of the brick and has had very little chemical action upon the particles themselves. Chemical action in the case of the clay brick was much more severe on the bonding material, or plastic clay, that was used than upon

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*Chief Chemist, Harbison-Walker Refractories Co., Pittsburgh.

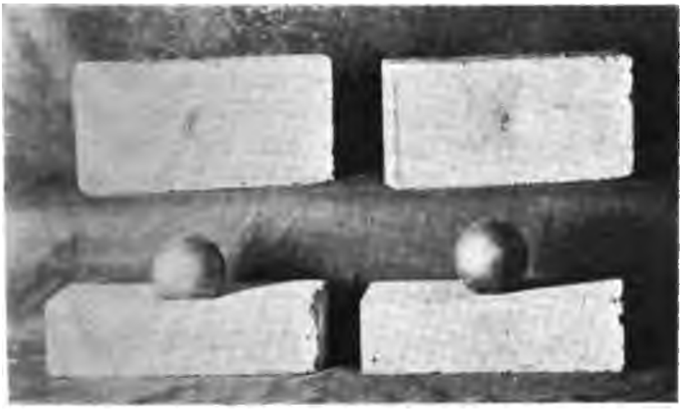

Fig. 14.

the flint clay ; in fact, in nearly every instance the flint clay stands out very definitely in these slag areas.

Chairman A. N. Diehl: As mentioned before, the practical testing of brick against purely chemical, is very important. About two years ago, I had the pleasure of hearing Dr. Unger explain his method of making practical brick tests, in which, he endeavored to subject the brick to the same operating conditions, which it would have to undergo in the usual practice. Dr. Unger, as far as I know, was the first to advance on so large a scale, this application of testing. Many of the methods were very ingenious, as the explanation which Mr. Nesbit has given, indicates. We would like to hear further from Dr. Unger, relative to his ideas on the subject.

Dr. J. S. Unger*: We have been working on this brick question for a number of years. About ten years ago a committee was appointed by our President to investigate the manufacture of brick. We learned quite a lot by visiting almost every brick plant in the vicinity of Pittsburgh, and we found that brick making was largely a question of traditions, and that is perhaps the real reason that there has not been the advancement in the art we usually expect in most businesses.

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*Manager, Central Research Bureau, Carnegie Steel Company, Pittsburgh.

After our visits we believed we knew what constituted a good brick and we prepared specifications to control the manufacture of bricks of that kind, and put them into actual service. These bricks were superior to any bricks we had tried for a similar purpose before, but they were not enough superior to justify the extra cost we were compelled to pay for them. We decided that perhaps we had put ourselves in the wrong position, the position of a brickmaker, which was not within our province, and that we should say to the brick maker: "Here is what we want—produce it."

As a consequence we began the study of high grade fire bricks in an entirely different way. We knew the ordinary tests made by the Ceramist consisted of making chemical analyses, the determination of the percentage of porosity and absorption, specific gravity, and the fusion or softening point. We felt that such tests were not giving us the necessary information to determine when we had a good brick. We believe the only way to test a brick is to imitate the conditions the brick is going to be subjected to in actual service, making the tests so much more severe that we could tell in a reasonably short time what we might expect from a brick, in actual service after a period of one to five years. Some blast furnace brick are in service for more than five years with no opportunity for examination from the time they are put into the blast furnace until the furnace is blown out.

Take the blast furnace bricks as an example. The bricks at the top of the blast furnace do not necessarily have to be highly refractory. The average top temperature of 160 blast furnaces, showed it to be about 500 degrees Fahr. The blast furnace top bricks are subject to other service conditions than that of heat. As the charge drops into the furnace, a portion strikes the wall or brick lining, which subjects the bricks to impact and abrasion. The blast furnace man attempts to prevent this wear by putting in cast iron bricks or even solid rings of cast iron.

The top bricks must also possess another quality, resistance to rapid thermal changes. The ore in the winter may be charged in a frozen condition, and when it strikes a brick at a temperature of 500 degrees, you can imagine what happens. At other times the charge may be soaked by rain. It became necessary to imitate such conditions in our tests.

After striking the wall, the charge begins to descend, and abrasion begins. It is necessary to imitate that action in our tests. A brick that is pretty well down in the furnace resists abrasion, slag penetration, heat, and changes in volume and pressure, all of which must be imitated.

In the bosh of the furnace, the slag and metal are molten, while the temperature is the highest of any portion of the furnace. A brick in this portion of the furnace must resist slag penetration, and it must not soften under high temperature.

In a regenerative chamber in an open hearth furnace, we have still another condition: a brick must have the property of picking up the heat quickly and delivering it up to the air when the checker chamber has been reversed. In the open hearth furnace, in addition to high temperature, we have the sand blast effect of the particles carried by the gases. At the end of the open hearth furnace in the bulk-head walls, silica bricks last but a short time. The little particles of lime and dust carried across the furnace, strike the walls and are deflected at right angles, and it is the slagging effect plus the sand blast effect that destroys the bricks in a short time.

During our studies it was necessary to devise tests to imitate all these conditions. Our tests for the last three years have really taught us more than our seven years' previous studies, and have convinced us that we have to make tests to suit service conditions. The aim of all this work is to prepare specifications for brick, the same as specifications are prepared for other products. We would like to say to the manufacturer of brick: "We want a brick able to withstand certain tests that we specify."

In addition, we studied the effects of such things which affect the quality of the brick during manufacture, as the coarseness or fineness of grinding, the influence of the amount of water added to the material, the influence of pressure in shaping the brick, and the influence of burning. A brickmaker must use the raw materials that are at hand. I want to say that I believe what we would ordinarily call an inferior clay, by being well made and combining every possible good feature that can be combined, can be made into a better brick than a high-grade clay made in an inferior manner.

To do this work it was necessary to work in conjunction with the brick maker. We have been fortunate in securing the services of our brick friends, who were willing to aid us in every particular. We have made brick experimentally, not one or two, or a dozen, but by the thousand, to prove certain things. By this method we were able to obtain information which we believe is of great value to the producer and user.

Chairman A. N. Diehl: Iron oxide behaves differently in different refractories. While it is, more or less, detrimental beyond a certain percentage, to clay and silica brick, due to its fluxing qualities, yet to a certain extent the iron oxide makes possible the superior qualities of the Austria-Hungarian magnesite. In the Austrian magnesite the iron runs in the neighborhood of 6 to 8 percent, and is constitutionally bound, thereby making it possible to burn in the bottom of the open-hearth furnaces without separation. The pure California and Grecian magnesite will not bind up as well, due to lack of iron oxide. Attempts have been made to mix magnesite with oxides, but the mixture is mechanical and results are not nearly as consistent as with the natural combination. I think Mr. Pierce can give you further information on this subject.

Mr. R. H. H. Pierce: I might say that there is a vast difference apparently in the bonding power of the natural chemically combined iron and the admixture of iron ore, or artificial iron, as you might say, with the magnesite. If the particles are not extremely finely ground a definite white spot or core may be seen in the Grecian magnesite or Californian, both of which are of the amorphous variety. They are apparently the same kind of deposit. The Austrian magnesite carries its iron chemically and its bond is very much stronger when burned.

I would like to add just a word on the use of a magnesite brick, and that is as to the action of moisture, and especially steam, upon the magnesite brick. This point really should have been made earlier in the discussion. We have found cases where magnesite brick have failed in heating up in a furnace, and on investigation showed that the brick were wet when the fires were lighted in the furnace. Steam in any form is very detrimental to magnesite brick. In fact, magnesite, no matter how thoroughly calcined, or, as we say, dead-burned, will hydrate very rapidly in the presence of steam even at atmospheric pressures, and increasingly rapidly with steam under high pressure. In fact, the hydration is almost complete, and the magnesite brick of any variety, of any burn, will come out of the steam chamber hydrated to an impalpable powder in a matter of just a few hours. There are cases in which magnesite brick are laid where they may not be thoroughly dry when the furnace is heated up. Steam is generated and perhaps included under slight pressure. The brick naturally becomes hydrated. That is exactly what takes place in the air in the case of dolomite brick. It seems impossible to so burn lime, even in low lime dolomites, that it will not hydrate under atmospheric conditions.

The question of tar bond for dolomite is one merely of handling in the green state. As soon as the brick is fired in the kiln the tar is burned or driven off and it has no further effect. It is only a question of being able to set such a brick that the tar bond is used at all. Apparently further than that it has no value.

There are various attempts at the present time to calcine dolomites satisfactorily. Some experimenters have tried to coat them over with various slags and protective materials; all have apparently failed. The dolomite grains slake after a very short exposure to the atmosphere. If a brick of that kind is ever successfully made, in the light of our present knowledge, it will probably be a question of placing that brick immediately into a furnace and firing it, and when the furnace goes out and the brick are allowed to cool the usual slaking is to be expected. That is not a very profitable undertaking.

Chairman A. N. Diehl: We have discussed the question from the brick end principally, and now should have some discussions on the use of refractories in the loose form. Just at present the steelmakers are going from one plant to another, inquiring from their friends as to the supply of magnesite and chrome ore, and are endeavoring to locate a substitute. There are all kinds of nostrums being tried out, and the various manufacturers are endeavoring to solve the problem in the easiest way. I would think for that reason a meeting like this should be in strong demand and quite a lot of discussion come out. We would like to hear from some of our open-hearth friends relative to their maintaining a high production, at the same time preserving their bottoms and banks.

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THE DESIGN OF SYMMETRICAL HINGELESS CONCRETE ARCHES

By VICTOR H. COCHRANE*

SYNOPSIS

The object of this paper is to develop a series of formulas and diagrams for use in making preliminary and final designs for symmetrical hingeless concrete arches in accordance with the elastic theory.

In Part *I* the difficulties and uncertainties involved in applying the elastic theory are enumerated; and approximate, rather than theoretically exact, methods of design are advocated. It is pointed out, however, that the variations from exactness due to the approximations proposed herewith are of little consequence in comparison with those due to certain approximations in common use. The factors affecting the values of the thrusts and moments are briefly discussed and the proposed methods of design are outlined.

In Part *II* the most desirable geometrical form for the arch axis is considered, and equations are derived giving approximately the best shape of axis for both open spandrel and filled spandrel arches.

Part *III* contains a discussion of the proper thickness of the arch ring in the haunch for given thicknesses at crown and springing. A series of typical arches is chosen applicable to any span length, rise-ratio, thickness at crown and springing, or manner of loading. The characteristics of these typical arches are then given, including the relative thicknesses, the areas of vertical faces, the lengths of the half-axes, the values of the constant $\Delta s \div I$ in terms of the moment of inertia I_0 at the crown, and the location of the centers of divisions such that the ratio of the length of each division to the moment of inertia of the section at the center of the division is equal to the constant $\Delta s \div I$.

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In Part *IV* influence line diagrams are given for the crown and springing sections of both open and filled spandrel typical arches, applicable for ordinary cases to any span length, rise-ratio, or live load. Several interesting features of these diagrams are discussed, including the four typical loadings producing maximum moments, and the variation in moments and thrusts with respect to the rise-ratio and also with respect to the ratio of springing thickness to crown thickness.

Part *V* contains formulas giving the values of the maximum thrusts and moments at crown and springing due to live loads, temperature variations, and the shortening of the arch. Approximate formulas are given for the dead load thrusts. These formulas, like the influence line diagrams, apply to both open and filled spandrel arches of any span length, rise-ratio, or live load. The steps required in designing an arch by means of the formulas are enumerated.

In Part *VI* there is developed an approximate method for correcting the maximum moments in case the actual arch axis deviates considerably from the assumed axis.

In Part *VII* are given five examples showing the application of the formulas and diagrams. Computations by other methods for four of the arches considered are to be found in engineering literature, and the results by these methods are stated for the sake of comparison.

Part *VIII* contains a list of cases in which it is believed the use of the formulas and diagrams herewith will be found to effect a great saving in time and labor.

PART I

GENERAL CONSIDERATIONS

It has become the customary practice to design plain and reinforced concrete hingeless arches by what is called the elastic theory, and the necessary formulas are given in many works in current use. Many analytical and graphical methods of applying these formulas have been developed, and they all give practically the same results. The application of one of these methods to the design of a given arch requires a great deal of time and labor, especially if the derivation of the formulas and the mathematical processes must first be verified. Of course the experienced computer will have become so familiar with the various steps required, and will have learned so to systematize his work, that the labor involved in making the computations for an arch will not be formidable. Many engineers who are called upon to design an arch have not had any experience in such work, and therefore they must spend a considerable time in acquiring a working knowledge of the application of the theory before beginning to make the computations. In many cases, too, the engineer has occasion to design arches so infrequently that in the intervals he forgets the theory and must review it each time, which is annoying when, as is usually the case, it is necessary to complete the design quickly.

But perhaps the most serious objection to the customary methods of design is that they are tentative. The form and dimensions of the arch must be assumed in advance, and then calculations made to determine the maximum unit stresses. If the stresses so determined prove to be much greater or less than desired the arch has not the proper shape or dimensions, and consequently these must be altered and new computations made. The results obtained in the first trial will usually indicate what changes are necessary to bring the stresses within the desired limits, but occasionally even the second trial will not give entirely satisfactory results. On this account the arch is often left as originally assumed, although the stresses may be considerably different from the predetermined working stresses. It will be seen, therefore, that it would be of great advantage to have a method whereby the dimensions of the arch could be fixed in advance with the practical certainty that the stresses as finally determined by the usual methods of analysis will not be materially different from the desired values. It was in order to work out such a method that the writer made the investigations of which this paper is the outcome. It is believed that the formulas and diagrams herewith are of sufficient accuracy to use for the final design in many cases, and that in practically all instances they will afford a means of determining the form and dimensions of the arch with assurance that the final analysis will show that but slight changes, if any, are required.

There are many reasons for concluding that the use of rigidly exact theoretical formulas for arch design is wholly unwarranted, and that if by making certain reasonable practical assumptions we can devise greatly shortened methods of design, we are quite justified in so doing. For, in the first place, the elastic theory as applied to hingeless arches is based on the assumption that the ends of the arch are rigidly attached to immovable abutments, so that a section of the arch at the skewback or springing is subject neither to vertical or horizontal displacement nor to rotation. This assumption is never in entire agreement with actual conditions, and is only admissible as an approximation in cases where the piers or abutments will, by reason of their size and the character of the foundations, be subject to but slight distortions or movements. There are other approximate assumptions made in deriving the working formulas, such as that the material is homogeneous, that the modulus of elasticity is constant, and that the effect of the radius of curvature may be neglected. Furthermore, it is necessary to replace the definite integrals of the three equations of condition by summations. But this is not all. Even if the thrusts and moments at any section for any given condition of loading, etc., could be found with certainty by the elastic theory the resultant stresses could not even then be exactly determined, on account of the approximate character of the flexure formulas and the uncertain tensile stresses in the concrete. Finally, it may be pointed out that the live load itself is subject to much uncertainty, both as to its amount and its distribution, and that the effect of variations in temperature, while in many cases quite severe, cannot in the present state of our knowledge concerning the matter be determined with any great degree of certainty. The effect of the shrinkage of the concrete is even more uncertain. These and other like considerations justify the use of approximate short-cut methods such as those proposed herein.

It may be mentioned here that some text-books in current use, while presenting a satisfactory theoretical treatment of the subject, give such meager information regarding its practical application as to lead the inexperienced designer astray. Thus it is sometimes stated that it is customary to compute the stresses for two positions of the live load, viz., over the half-span and over the whole span. Now one of the most highly stressed sections is generally that at the crown, and for this section the above distributions of the live load produce about the smallest extreme fiber stresses of any that could be chosen.

It is asserted by some writers that for a flat segmental arch the moments and thrusts may be assumed to be the same as for a parabolic arch whose moment of inertia varies as the secant of the angle of inclination. This assumption, while in some cases fairly satisfactory so far as the live load is concerned, is wide of the mark in respect to temperature and arch-shortening thrusts and moments, which are comparatively large for flat arches. Other writers apparently advocate the use of parabolic arch formulas for all kinds of arches, but the stresses so determined are often quite different from the stresses figured by the so-called exact method, and sometimes inconsistent results are obtained, such as when the resistance line is found to lie wholly above, or wholly below, the arch axis. The methods of design proposed in this paper will give stresses much nearer those obtained by the more exact method.

In some designs the effect of the arch shortening has either been neglected altogether or included with the temperature effect. It is evident that the arch-shortening effect should be considered in connection with every combination of stresses. Hence it is incorrect to assume the following combinations of stresses, as is sometimes done:

1. Dead load and live load.

2. Dead load, live load, arch shortening, and temperature.

The arch-shortening effect is different for each different combination of loading, whereas it is commonly assumed to be the same.

The writer does not wish to be understood to imply that such approximations as those just mentioned, which are found in some standard text-books and which have been adopted in the design of a number of important structures, lead to unsafe or otherwise unsatisfactory designs. It is desired merely to point out that the accompanying diagrams and formulas will produce better and more consistent results than will methods of design based on such approximations.

In other fields of design approximate methods are in use, which, while resulting in satisfactory designs, do not, in the opinion of the writer, give stresses as nearly in agreement with actual conditions as do the formulas and diagrams given in this paper. For instance, in designing steel trusses, the secondary stresses, amounting in some cases to a large percentage of the primary stresses, are often neglected. Also, in computing the stresses in trusses of swing spans the reactions are usually taken as for a girder having a constant moment of inertia, although the moment of inertia may vary greatly. We need not, therefore, hesitate to make use of the formulas or diagrams herewith if we find that the moments and thrusts as given by them are in fairly close agreement with those obtained by the more exact methods in current use.

What the writer has tried to do is to obtain a series of co-efficients for symmetrical arches such that for any given span length, any given rise, and any given loading, the thrusts and moments may be found approximately and the thickness of the arch rib determined. These co-efficients are somewhat similar to those which have been worked out for moments and shears in continuous beams and slabs for various conditions of loading, and which have proved so useful.

The values of the moments and thrusts due to live loads depend upon the following factors:

1. The live load w per lin. ft. of arch (w may be different for different sections of the arch rib).

2. The span length l of the arch axis.

3. The ratio r of the rise to the span of the axis.

4. The ratio of the moment of inertia of the arch rib at various sections to the moment of inertia at the crown. It is not necessary to know the moments of inertia; merely the manner of variation along the arch axis is required.

5. The geometrical form of the arch axis.

The live load moments may be found in terms of wl^2, and the thrusts in terms of wl; hence the first two factors enumerated above may be disregarded, the moments and thrusts being determined in all cases as co-efficients of wl^2 and wl, respectively. These co-efficients will then depend upon factors 3, 4 and 5.

In order to determine the effect of factors 3 and 4, the writer calculated a large number of arches, all having the same span length. The ratio of the thickness of the arch at the springing to that at the crown,

$$\frac{t_s}{t_o}$$

(Fig. 3), designated below by the symbol u_s, was assumed to have several different values, and the intermediate thickness ratios

$$u = \frac{t_x}{t_o}$$

(Fig. 3) were assumed according to the diagrams in Fig. 5, to be discussed later. The values of u_s chosen were 1.5, 2, 2.5 and 3. For each value of u_s three different rise-ratios were assumed, and in each case influence lines for moments and thrusts were obtained by calculation. In all of these cases the geometrical form of the arch axis was assumed according to the definite equations (12) and (15) below. Thus was determined the influence of all the variables affecting the moments and thrusts for the particular arch axes assumed.

The geometrical form of the arch axis should be different for each different distribution of the loads, especially the dead loads. For this reason hardly any two arch axes have or should have exactly the same shape. Given two arches of the same rise and span, one having open spandrels and the other having filled spandrels, and the two axes will be quite different in shape. For slight changes in the shape of the arch axis there is not much change in the maximum live load and temperature moments and the corresponding thrusts. It is possible to write an equation for the axes of open spandrel arches such that for any particular arch the curve determined by the formula will lie fairly close to the most desirable axis. A similar equation for filled spandrel arches may be derived. Such being the case it appears that the moments and thrusts for the assumed axes will not differ much from those for the actual axes, and such differences as may exist may be largely compensated for by the use of an approximate method of correction to be explained below.

This paper will be confined to the consideration of symmetrical arches, a large majority of arches being of this descripton.

The foregoing general statements in regard to the need for methods whereby arches may be designed quickly, and in regard to the proposed solution of the problem, will now be supplemented by a more detailed account of the development of the formulas and diagrams proposed for use.

PART II

THE MOST DESIRABLE GEOMETRICAL FORM FOR THE ARCH AXIS

In an arch having a parabolic axis and loaded with a uniform live load *w* per lineal foot over the whole span, the moment at any section of the arch is equal to zero (provided the effect of the shortening of the arch is neglected), since the resistance line for a uniform load is a parabola coincident with the arch axis. The maximum positive and negative moments at any section due to partial loadings are equal; for if the live load producing the maximum positive moment is placed on the span, and then the remainder of the span is loaded, the negative moment produced by this additional load will be numerically equal to the positive moment due to the original loading, since the algebraic sum of the two moments must be equal to zero. In this paper the moments producing compressive stresses in the upper fibers of an arch will be called positive, and those producing compressive stresses in the lower fibers will be considered negative.

In all ordinary cases the most desirable arch axis lies above the parabolic axis of the same span and rise. Hence for an arch having an axis of the most desirable form the maximum positive and negative live load moments at any section are no longer numerically equal. At the crown and springing sections the maximum live load positive moments are greater than the maximum live load negative moments. At certain sections in the haunch the negative moments exceed the positive. It might seem, therefore, that it is desirable to make the arch axis of such form that the total maximum positive and negative moments due to live and dead loads combined will be equal. To accomplish this the dead load moment at each section must be equal to minus one-half the algebraic sum of the maximum positive and negative live load moments, that is, equal to minus one-half the moment due to live load over the whole span; or, what amounts to the same thing, equal to minus the moment due to one-half the live load over the whole span. Consequently, if we make the arch axis coincident with the funicular, or equilibrium, polygon for dead load plus one-half the live load over the entire span this condition is fulfilled, for taking off the half live load will produce moments equal to minus the moments due to one-half the live load over the whole span.

The arch curve determined in this manner will lie between a parabola, which is the linear arch for the half live load over the entire span, and the dead load equilibrium polygon through the centers of crown and springing (as for a three-hinged arch). It will generally lie much closer to the latter than to the former, because the dead load thrusts are usually much greater than the thrusts due to the half live load. Hence the arch axis determined by this rule will differ but little from the equilibrium polygon for dead load only. It is, of course, generally impracticable to make the arch axis coincide exactly with the equilibrium polygon for dead load plus one-half live load, or with that for dead load only.

So far no account has been taken of the shortening of the arch axis, which gives rise to large positive moments at the crown, and larger negative moments at the springing. Consequently, if in the case of an arch whose axis is laid out to fit the funicular polygon for dead load plus one-half live load, the effect of the arch shortening is included, the maximum positive and negative moments are no longer equal except at the two contraflexure points near the quarter points of the arch. The arch shortening moments are so large that, except possibly for arches of large rise-ratio, the above method for determining the axis offers no advantages over the more simple rule of making the arch axis conform as closely as practicable to the dead load equilibrium polygon through the centers of crown and springing, determined as for an arch having hinges at these points. The writer believes that the latter rule is generally preferable to the former, but whichever method is followed the axes will differ so little that the live load and arch shortening moments will be practically the same for both axes.

Making the arch axis conform to the dead load equilibrium polygon is of benefit at the springing, for since the live load positive moment is greater than the negative, the total moments are more nearly equalized. At the crown, unfortunately, the reverse is true, and the maximum total moments are more unequal than for an arch axis determined by the dead load and half live load. However, since in any case the arch must be greatly thickened near the springing, it seems desirable to favor the springing rather than the crown section, and hence it will be found that satisfactory results are obtained by making the arch axis conform to the equilibrium polygon for dead load. To do so is of great advantage in other respects. In the first place, it is obvious that since the dead load moments are usually equal to zero, or are small in comparison with the moments induced by arch shortening, the former do not need to be computed at all. If desired, an arbitrary allowance may be made for the dead load moment at any section, depending upon the closeness with which the arch axis may be made to fit the dead load equilibrium polygon, but ordinarily the dead load moments will be negligible in comparison with those due to live load, arch shortening, and temperature variations, and so may be disregarded.

We shall now derive equations for the arch axes, to be used in making the calculations for the influence lines and formulas. From what has been said above it is evident that these equations may be derived with regard to the dead loads only. The dead loads for filled spandrel arches are so different from those for

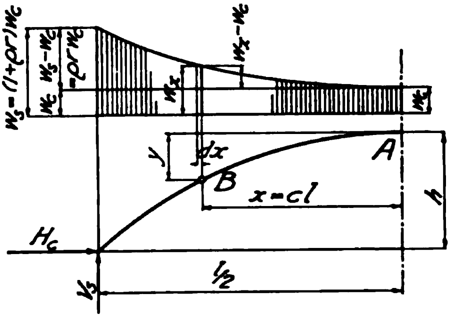

Fig. 1. Loading for Linear Arch.

open spandrel arches that an equation will be required for each of these two kinds of arches.

In Fig. 1 let the dead load of the half-arch be represented by the shaded area, and let

l = the span length.
h = the rise of the axis.
r = the rise ratio $h \div l$.
w_c = the dead load per lineal foot of span at the center of the span, or crown.
w_x = the dead load per lineal foot of span at a point distant x feet from the center of the span.
w_s = the dead load per lineal foot of span at the springing.

The value of the total *increase* of load per lineal foot ($w_s - w_c$) will vary approximately as the rise-ratio r. Hence we may assume $w_s - w_c = prw_c$, p being a constant and equal to

$$\frac{\frac{w_s}{w_c} - 1}{r}$$

By plotting curves representing the dead loads for a considerable number of arches actually designed and built, it is found that the increase in load $w_x - w_c$ varies in the case of open spandrel arches approximately as the square of the distance x from the crown, and in the case of filled spandrel arches approximately as the cube of the distance x from the crown. Hence for open spandrel arches,

$$w_x = w_c\left(1 + 4\,pr\frac{x^2}{l^2}\right) \dots\dots\dots\dots\dots\dots (1)$$

For filled spandrel arches,

$$w_x = w_c\left(1 + 8\,pr\,\frac{x^3}{l^3}\right) \dots\dots\dots\dots\dots\dots (2)$$

Let us now derive the equation of the linear arch for open spandrel arches referred to the crown as origin. The total load W_x between the crown A and a point B distant x from the crown (Fig. 1) is found from equation (1), thus:

$$W_x = \int_0^x w_x dx = w_c \int_0^x \left(1 + 4pr\frac{x^2}{l^2}\right)dx = w_c x\left(1 + \frac{4prx^2}{3l^2}\right) \dots (3)$$

The total weight V_s of the half span is given by the equation

$$V_s = w_c l\,\frac{3 + pr}{6} \dots\dots\dots\dots\dots\dots (4)$$

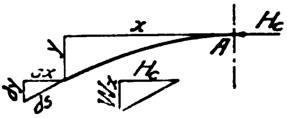

Fig. 2. Forces Acting on a Portion of the Linear Arch.

The moment of the total load W_x about point A is given by the equation

$$M_x = \int_0^x w_x . x dx = w_c \int_0^x (x dx + \frac{4\rho r x^3}{l^2} dx)$$

or $M_x = w_c x^2 (\tfrac{1}{2} + \frac{\rho r x^2}{l^2})$ ....(5)

The moment M for the half span load is given by the equation

$$M = \frac{w_c l^2}{16}(2+\rho r) \qquad (6)$$

$$\therefore H_c = \frac{\frac{V_c l}{2} - M}{h} = \frac{\frac{w_c l^2}{12}(3+\rho r) - \frac{w_c l^2}{16}(2+\rho r)}{rl}$$

or $H_c = w_c l \dfrac{6+\rho r}{48\, r}$ ....(7)

From Fig. 2 it is evident that

$dy : dx = W_x : H_c$

$$\frac{dy}{dx} = \frac{W_x}{H_c} = \frac{w_c x\left(1 + \frac{4\rho r x^2}{3l^2}\right)}{\frac{w_c l}{48 r}(6 + \rho r)}$$

$$= \frac{16 r}{l^3(6+\rho r)}(3l^2 x + 4\rho r x^3)$$

Integrating,

$$y = \frac{16\, r}{l^3(6+\rho r)} \int_0^x (3l^2 x \, dx + 4\rho r x^3 dx)$$

$$= \frac{16\, r x^2}{l^3(6+\rho r)} (\frac{3l^2}{2} + \rho r x^2)$$

or, putting $x = cl$, we have the following equation for the linear arch:

$$y = \frac{8rl}{6+\rho r}(3c^2 + 2\rho c^4 r) \qquad (8)$$

in which $\rho r = \frac{w_s}{w_c} - 1$

If $w_s = w_c$, $\rho r = 0$ and

$$y = 4c^2 rl = 4c^2 h,$$

which is the equation of a parabola, the linear arch for a uniform load over the whole span.

In a similar manner we get the following equations for filled spandrel arches:

$$V_s = w_c l \frac{4 + \rho r}{8} \qquad (9)$$

$$H_c = w_c l \frac{10 + \rho r}{80\, r} \qquad (10)$$

$$y = \frac{8\, rl}{10 + \rho r}\,(5c^2 + 4\rho c^5 r) \qquad (11)$$

An examination of the dead loads for a considerable number of arches of all kinds showed that the approximate average values of ρ may be assumed as follows:

For open spandrel arches, $\rho = 5$.

For filled spandrel arches, $\rho = 30$.

The influence lines and formulas were based on these values of ρ, the equations of the arch axes and the equations for the approximate vertical and horizontal dead load reactions V_s and H_c being as follows:

For open spandrel arches:

$$y = \frac{8\, r\, l}{6 + 5r}\,(3c^2 + 10c^4 r) \qquad (12)$$

$$V_s = w_c l \frac{3 + 5r}{6} \qquad (13)$$

$$H_c = w_c l \frac{6 + 5r}{48r} \qquad (14)$$

For filled spandrel arches:

$$y = \frac{4\, r\, l}{1 + 3r}\,(c^2 + 24c^4 r) \qquad (15)$$

$$V_s = w_c l \frac{2 + 15r}{4} \qquad (16)$$

$$H_c = w_c l \frac{1 + 3r}{8r} \qquad (17)$$

The value of ρ may change considerably without making much change in the arch axis. Thus if in equation (8) we assume $l = 100$ and $r = 0.20$, we get the following values of y for the values of ρ and c in the table:

Values of		Values of y for	
ρ	$c = 0.20$	$c = 0.30$	$c = 0.40$
3	2.96	6.78	12.38
4	2.88	6.66	12.26
5	2.81	6.54	12.14
6	2.75	6.43	12.03
7	2.69	6.33	11.93

The final arch axis in any case will be laid out to fit the equilibrium polygon for dead load or that for dead load plus half live load, as seems most suitable. The method of passing an equilibrium polygon for given loads through two given points, such as the centers of the crown and springing sections, is well known and will not be given here. The pole distance for the force polygon is equal to the horizontal thrust drawn to the same scale as the load line, and it may be quickly computed by dividing the moment of the loads and vertical reaction at the end, about the center of the crown, by the rise of the arch axis. The vertical reaction for a symmetrical arch is, of course, equal to the sum of the half-span loads.

PART III

THE VARIATION IN THE THICKNESS OF ARCH RIBS

There are in use several empirical formulas for determining in advance the required thickness of the arch at the crown, but while some of these give good results, none of them takes into account all of the many factors affecting the thickness of the arch. By the use of the formulas given in this paper any assumed thickness at the crown, whether determined by one of the empirical formulas referred to above or by comparison with the thickness actually used for a similar span, may be quickly verified.

The ratio of the thickness at the springing to that at the crown varies considerably. Let u = the ratio of the thickness at any point to the thickness at the crown, so that

$$u = \frac{t_x}{t_0} \text{ (Fig. 3),}$$

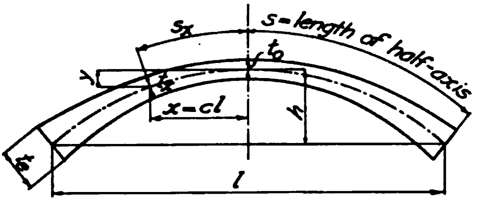

Fig. 3. Dimensions of Arch Rib.

in which t_x = the thickness at the given point
and t_0 = the thickness at the crown.

Also let u_s denote the value of u for the section at the springing, so that

$$u_s = \frac{t_s}{t_0} \text{ (Fig. 3).}$$

An examination of the designs for a large number of arches actually built shows that u_s has been made to vary from about 1-1/3 as a minimum to about 4½ as a maximum. The latter value appears to be excessive.

In Fig. 3, let

s = the length of the half-axis, measured along the axis from the crown to the springing.

s_x = the distance along the axis from the crown to a given section the abscissa of which = x.

Also let

v = the ratio $\frac{s_x}{s}$.

Then as v varies from 0 to unity, u varies from unity to the value u_s. The manner in which u varies as v increases is of interest and importance. A study of actual examples shows that there has been a surprising diversity of practice in this respect. In some cases we find the relation

$$u = 1 + (u_s - 1)\, v,$$

which is the equation of a straight line. In other cases the law of variation is expressed by the equation

$$u = 1 + (u_s - 1)\, v^2,$$

which is the equation of a parabola. In some cases there does not seem to be any definite law of variation.

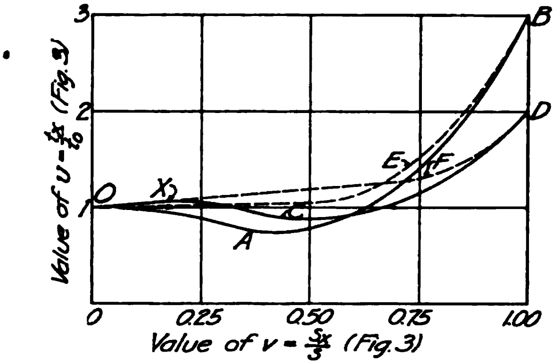

Fig. 4. Diagrams Showing Minimum Thickness of Arches.

The writer made a number of complete designs and investigated a number of designs found in technical literature, in order to determine what the thicknesses of the arch should be at various points in the haunch to give the same fiber stresses as at the crown and the springing; or in other words, to determine the variation in u with respect to v for equal maximum stresses throughout the arch ring. Plotting the values of v as abscissas with the values of u as ordinates, curves were obtained of which those shown in the full lines *OAB* and *OCD* in Fig. 4 are typical. In each case it was found that a certain portion of the haunch might, so far as the stresses were concerned, have been made thinner than the crown section. It was also found in each case that the thinnest section required is at about the quarter point, and that between this point and the springing the thickness should increase almost uniformly. It is easy to see why this should be the case, since the moments due to rib shortening and temperature variations are small near the quarter point and greatest at the crown or springing. A slight increase of thickness was required near the crown, as shown at *X* in *OCD,* in some arches of large rise-ratio designed for a relatively heavy live load.

An arch of this shape would be unsightly and difficult to build, and consequently about the best that can be done is to make the arch rib of uniform thickness, or but slightly increasing thickness, from the crown to about the quarter point, and to increase the thickness almost uniformly from this point to the

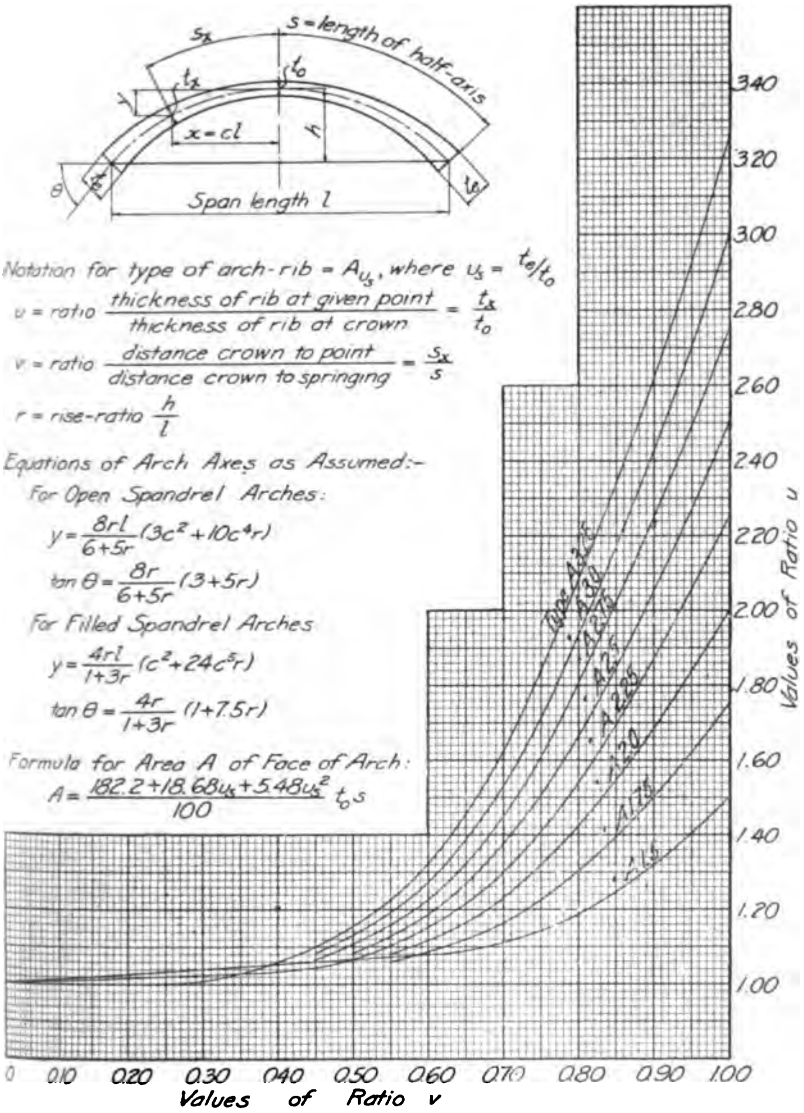

Fig. 5. Assumed Thickness of Typical Arches and Equations of Assumed Linear Arches.

springing. The point at which the thickness should begin to increase rapidly is nearer the springing in arches of large rise-ratio carrying heavy live loads than in flat arches carrying light live loads. The dashed curve *OFD* in Fig. 4 represents an arch of the former kind and the curve *OEB* an arch of the latter kind, these curves representing the actual thicknesses to be used instead of the possible minimum thicknesses shown by *OCD* and *OAB*. The flatter arches generally require a greater relative thickness at the springing than do those with large rise-ratios.

These conclusions led to the selection of a number of typical curves showing the variation of u with respect to v for various values of u_s. These curves are shown in Fig. 5 and are designated as Types $A_{3.25}$, A_3, $A_{2.75}$, $A_{2.5}$, $A_{2.25}$, A_2, $A_{1.75}$, and $A_{1.5}$, the subscript in each case denoting the value of u_s for that type. These curves were chosen after a careful study of existing well-designed arches, and it is believed that the arch thicknesses required in any given case will be closely represented by some one of them; we have only to select the one best suited to the given conditions.

Since in each case the typical arch has a greater thickness in the haunches than would be required to keep the extreme fiber stresses within desired limits, we reach the important conclusion that it is unnecessary to compute the stresses in any but the crown and springing sections. The writer has yet to find a single well-designed arch having thicknesses corresponding closely to those represented by one of these typical curves, in which the stresses at the crown and springing are not very nearly the maximum found anywhere in the arch, provided the arch-shortening effect is considered. Perhaps the only good reason for computing the stresses anywhere except at these two sections is in order to determine whether the amount of the steel reinforcement may be reduced near the quarter point.

Many arches have been built having a much greater relative thickness in the haunch than indicated by these diagrams, but such practice is not to be recommended. Not only do such arches require more material than necessary, but on account of the thicker haunches have greater arch-shortening and temperature stresses at the crown and springing sections than do those having thicknesses corresponding to the diagrams. Thickening the haunch does not seem to improve the appearance of the arch. It is therefore clearly advisable to make the haunch as thin as practicable.

If the half axis is divided into ten equal sections the ratio of the depth of the arch at the center of each section to the depth at the crown is given in the following table:

TABLE I.

THICKNESSES OF TYPICAL ARCHES.

Value of v	Values of u for Type							
	$A_{1.5}$	$A_{1.75}$	A_2	$A_{2.25}$	$A_{2.5}$	$A_{2.75}$	A_3	$A_{3.25}$
0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
0.05	1.007	1.006	1.005	1.004	1.003	1.002	1.001	1.000
0.15	1.021	1.018	1.015	1.012	1.009	1.006	1.003	1.000
0.25	1.035	1.030	1.025	1.020	1.015	1.010	1.005	1.000
0.35	1.049	1.042	1.035	1.028	1.023	1.021	1.023	1.030
0.45	1.063	1.054	1.048	1.048	1.057	1.070	1.083	1.101
0.55	1.077	1.072	1.085	1.105	1.133	1.165	1.193	1.231
0.65	1.095	1.125	1.168	1.215	1.269	1.328	1.385	1.455
0.75	1.145	1.223	1.311	1.403	1.508	1.625	1.737	1.865
0.85	1.245	1.393	1.547	1.700	1.862	2.025	2.185	2.355
0.95	1.406	1.621	1.837	2.055	2.277	2.495	2.709	2.932
1.00	1.500	1.750	2.000	2.250	2.500	2.750	3.000	3.250

We can readily obtain a formula for the areas of the vertical faces of these typical arches. This formula is

$$A = \frac{182.2 + 18.68u_s + 5.48\,u_s^2}{100}\,t_0 s$$

The value of s, the length of the half axis, may be determined by scaling from a drawing, or it may be taken by interpolation from the following table:

TABLE II.

LENGTHS OF THE HALF ARCH AXIS s IN TERMS OF THE SPAN LENGTH l.

Kinds of Arches.	Values of s for Rise-ratio r =				
	0.10	0.15	0.20	0.25	0.30
Open Spandrel Arches.	0.513 l	0.529 l	0.551 l	0.577 l	0.607 l
Filled Spandrel Arches.	0.515 l	0.534 l	0.559 l	......	......

The relative depths of the arch being assumed as in the diagrams, Fig. 5, the values of v for the centers of the divisions having a constant value of

$$\frac{\Delta s}{I}$$

were computed. The ratio of the total area of reinforcing steel at the crown to the area of concrete at the same point was assumed equal to 0.01, and the steel was assumed to be symmetrically disposed about the axis with the centers of the bars at one-tenth the depth of the rib from the exterior surfaces. The area of reinforcement at all other sections was assumed to be the same as at the crown. Then the relative moments of inertia were computed, that is, the ratios

$$\frac{I_o}{I},$$

I_0 being the moment of inertia at the crown and I the moment of inertia at the given section. The value of this ratio is unity for $v = {}^\circ$ and equal to or less than unity for all other values of v. If on squared paper we plot the ratios

$$\frac{I_o}{I}$$

as ordinates with the values of

$$v\ (= \frac{s_x}{s})$$

as abscissas and draw a smooth curve through the points, then in order to divide the half axis s into n divisions such that the ratio

$$\frac{\Delta s}{I}$$

for each division is a constant, we have only to divide the area under the curve into n equal parts. This is easily done with the aid of a slide rule. The area of the first part is

$$\frac{I_o}{I_1} \cdot \frac{\Delta s_1}{s};$$

the area of the second part is

$$\frac{I_o}{I_2} \cdot \frac{\Delta s_2}{s}$$

etc. Hence since the n parts have equal areas and I_0 and s are constant, we have

$$\frac{\Delta s_1}{I_1} = \frac{\Delta s_2}{I_2} = \frac{\Delta s_n,}{I_n}$$

that is, the ratio

$$\frac{\Delta s}{I}$$

is constant. The following values for 10 divisions of the half axis were computed:

TABLE III.

VALUES OF $\frac{\Delta s}{I}$ FOR TYPICAL ARCHES.

(Half Axis Divided into 10 Parts.)

Type	Value of $\frac{\Delta s}{I}$
$A_{1.5}$	0.0769 $s \div I_0$
$A_{1.75}$	0.0732 $s \div I_0$
$A_{2.}$	0.0699 $s \div I_0$
$A_{2.25}$	0.0672 $s \div I_0$
$A_{2.5}$	0.0647 $s \div I_0$
$A_{2.75}$	0.0626 $s \div I_0$
$A_{3.}$	0.0606 $s \div I_0$
$A_{3.25}$	0.0586 $s \div I_0$

The approximate value of s may be taken from Table II above.

The following table gives the location of the centers of divisions having a constant ratio $\frac{\Delta s.}{I}$ These points will be referred to for convenience as "division centers," or "centers of divisions."

TABLE IV.

LOCATION OF CENTERS OF DIVISIONS HAVING A CONSTANT RATIO $\frac{\Delta s}{I}$ (10 Divisions).

Point at Center of Division No. from Crown.	Values of v ($=\frac{sx}{s}$)for Type							
	$A_{1.5}$	$A_{1.75}$	$A_{2.}$	$A_{2.25}$	$A_{2.5}$	$A_{2.75}$	$A_{3.}$	$A_{3.25}$
1	0.039	0.037	0.036	0.034	0.033	0.032	0.031	0.030
2	0.119	0.112	0.107	0.102	0.098	0.095	0.092	0.089
3	0.201	0.190	0.180	0.172	0.165	0.159	0.153	0.149
4	0.286	0.270	0.255	0.243	0.232	0.222	0.214	0.208
5	0.374	0.352	0.332	0.316	0.301	0.287	0.275	0.265
6	0.464	0.436	0.411	0.389	0.370	0.353	0.338	0.325
7	0.558	0.522	0.491	0.466	0.443	0.423	0.405	0.389
8	0.657	0.614	0.578	0.549	0.524	0.502	0.481	0.463
9	0.766	0.722	0.684	0.652	0.625	0.600	0.578	0.558
10	0.912	0.890	0.872	0.856	0.842	0.829	0.817	0.806

To find the distances from the crown to the division centers, multiply the above co-efficients by the length of the half-axis. These co-efficients apply to an axis of any shape.

Table IV was computed on the basis of a one percent crown reinforcement, but it may be used for plain arch ribs, since the moments and thrusts are changed but little on account of a considerable change in the location of the division centers.

PART IV

THE INFLUENCE LINE DIAGRAMS

It is well known that the maximum extreme fiber stresses at any section occur under the loadings producing maximum moments about the core points of the section.* These maximum core-point moments will cause stresses only a little greater than those produced by the maximum moments about the center of the section, and hence it is permissible to figure the stresses for the latter moments only, thus greatly simplifying the work. The accompanying diagrams and formulas are adapted to this procedure.

The formulas used in figuring the influence line values were the same as given in Taylor and Thompson's "Concrete, Plain and Reinforced," p. 553, simplified by assuming $m = 10$ and dropping the terms containing M_R, the unit loads being on the left half only. These formulas thus reduce to the following:

$$H_c = \frac{10\Sigma M_L y - \Sigma M_L \Sigma y}{2[10\Sigma y^2 - (\Sigma y)^2]} \qquad (18)$$

$$V_c = \frac{\Sigma M_L x}{2\Sigma x^2} \qquad (19)$$

$$M_c = \frac{\Sigma M_L - 2H_c\Sigma y}{20} \qquad (20)$$

In the above formulas the terms Σx, Σy, $(\Sigma y)^2$, Σx^2, and Σy^2 are the summations for all the division points of the half axis, and are constant for any given arch. Thus the denominators of the expressions for H_c and V_c are constant for all positions of the unit load, depending only on the number and location of the

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***Plain and Reinforced Concrete Arches,* by Melan, tr. by Steinman, p. 21.

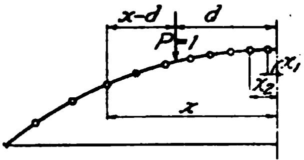


Fig. 6.

division points, that is, on the form and dimensions of the arch rib. The summations ΣM_L, $\Sigma M_L x$, and $\Sigma M_L y$ are for only those division points between the unit load and the springing, or for example to the left of the load in Fig. 6. Simple expressions may be found for these summations in the following manner:

In Fig. 6 let n = the number of division points to the left of the unit load P. Let d = the distance from the crown to the line of action of P. Now if we denote by $\Sigma' x$, $\Sigma' y$, etc., the summations for the division points to the left of the load, we have

$$\Sigma M_L = \Sigma'(x-d)$$
$$\Sigma M_L x = \Sigma' x(x-d)$$
$$\Sigma M_L y = \Sigma' y(x-d)$$

These expressions reduce to the following simple equations:

$$\Sigma M_L = \Sigma' x - nd \quad (21)$$
$$\Sigma M_L x = \Sigma' x^2 - d\Sigma' x. \quad (22)$$
$$\Sigma M_L y = \Sigma' xy - d\Sigma' y \quad (23)$$

Following is a typical set of calculations, being for a Type A_2 open spandrel arch having a span of 100 ft. and a rise of 20 ft. ($r = 0.20$). A twenty-inch slide rule and a table of squares were used:

Division Point No. from Crown	x	y	x^2	y^2	xy
1	1.98	0.03	3.9	.....	0.06
2	5.90	0.25	34.8	0.06	1.48
3	9.90	0.68	98.0	0.46	6.73
4	13.96	1.36	194.9	1.85	18.98
5	18.10	2.29	327.6	5.24	41.45
6	22.28	3.51	496.4	12.32	78.20
7	26.42	5.00	698.0	25.00	132.10
8	30.80	6.93	948.6	48.02	213.44
9	35.99	9.66	1295.3	93.32	347.66
10	44.60	15.44	1989.2	238.39	688.62
	209.93 $=\Sigma x$	45.15 $=\Sigma y$	6086.7 $=\Sigma x^2$	424.66 $=\Sigma y^2$	1528.72 $=\Sigma xy$

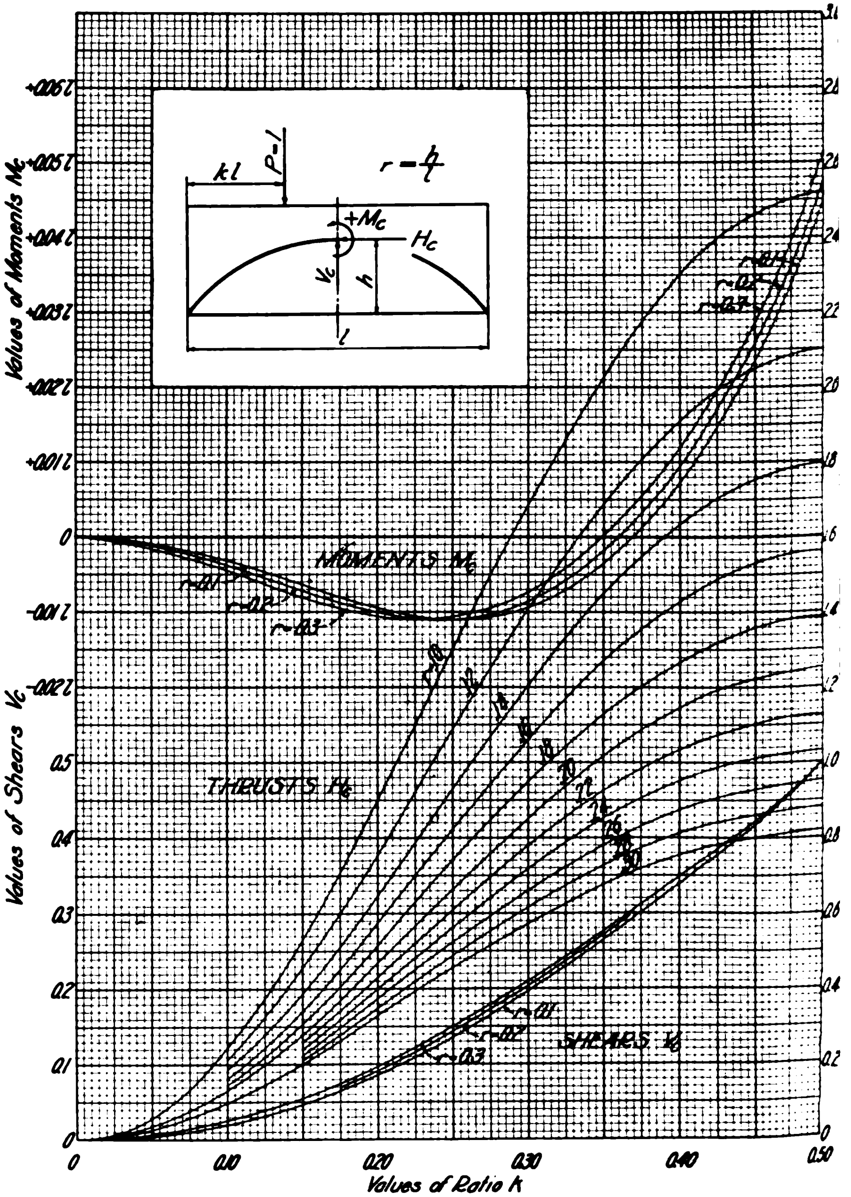


Fig. 7. Influence Lines for Moments, Thrusts and Shears at Crown; Open Spandrel Arch, Type $A_{1.3}$.

$(\Sigma y)^2 = 2038.5$
$2[10\Sigma y^2 \text{-} (\Sigma y)^2] = 4416.2$

d	n	$\Sigma' x$	$\Sigma' y$	$\Sigma' x^2$	$\Sigma' xy$	nd	$d\Sigma' x$	$d\Sigma' y$
0	10	209.93	45.15	6086.7	1528.7	0	0	0
5	9	207.95	45.12	6082.8	1528.7	45	1039.8	225.6
10	7	192.15	44.19	5950.0	1520.5	70	1921.5	441.9
15	6	178.19	42.83	5755.1	1501.5	90	2672.9	642.5
20	5	160.09	40.54	5427.5	1460.0	100	3201.8	810.8
25	4	137.81	37.03	4931.1	1381.8	100	3445.3	925.8
30	3	111.39	32.03	4233.1	1249.7	90	3341.7	960.9
35	2	80.59	25.10	3284.5	1036.3	70	2820.7	878.5
40	1	44.60	15.44	1989.2	688.6	40	1784.0	617.6
45	0	0	0	0	0	0	0	0

d	ΣM_L	$\Sigma M_L x$	$\Sigma M_L y$	$\Sigma M_L \Sigma y$	H_c	V_c	M_c
0	209.93	6086.7	1528.7	9478.3	1.315	0.500	+4.559
5	162.95	5043.0	1303.1	7357.2	1.285	0.4145	+2.345
10	122.15	4028.5	1078.6	5515.1	1.193	0.331	+0.721
15	88.19	3082.2	859.0	3981.8	1.044	0.2533	—0.304
20	60.09	2225.7	649.2	2713.1	0.855	0.1828	—0.856
25	37.81	1485.8	456.0	1707.1	0.647	0.1221	—1.031
30	21.39	891.4	288.8	965.7	0.435	0.0732	—0.894
35	10.59	463.8	157.8	478.1	0.249	0.0381	—0.594
40	4.60	205.2	71.0	207.7	0.114	0.01687	—0.284
45	0	0	0	0	0	0	0

From the values such as given in the last three columns influence line diagrams were plotted. A number of such diagrams are shown in Fig. 7 to Fig. 18, inc. Figs. 7, 8 and 9 are influence lines for moments, thrusts and shears at crown for open spandrel arches; Figs. 10, 11 and 12 are influence lines for moments and thrusts at springing for open spandrel arches; Figs. 13, 14 and 15 are influence lines for moments, thrusts and shears at crown for filled spandrel arches; and Figs. 16, 17 and 18 are influence lines for moments and thrusts at springing for filled spandrel arches. The thrusts and shears are in pounds and the moments in foot pounds; k is the ratio

$$\frac{\textit{distance from left springing to load}}{\textit{span length } l},$$

as indicated in Figs. 7, 10, 13 and 16.

The use of these influence line diagrams requires little explanation. The designer having determined by means of the

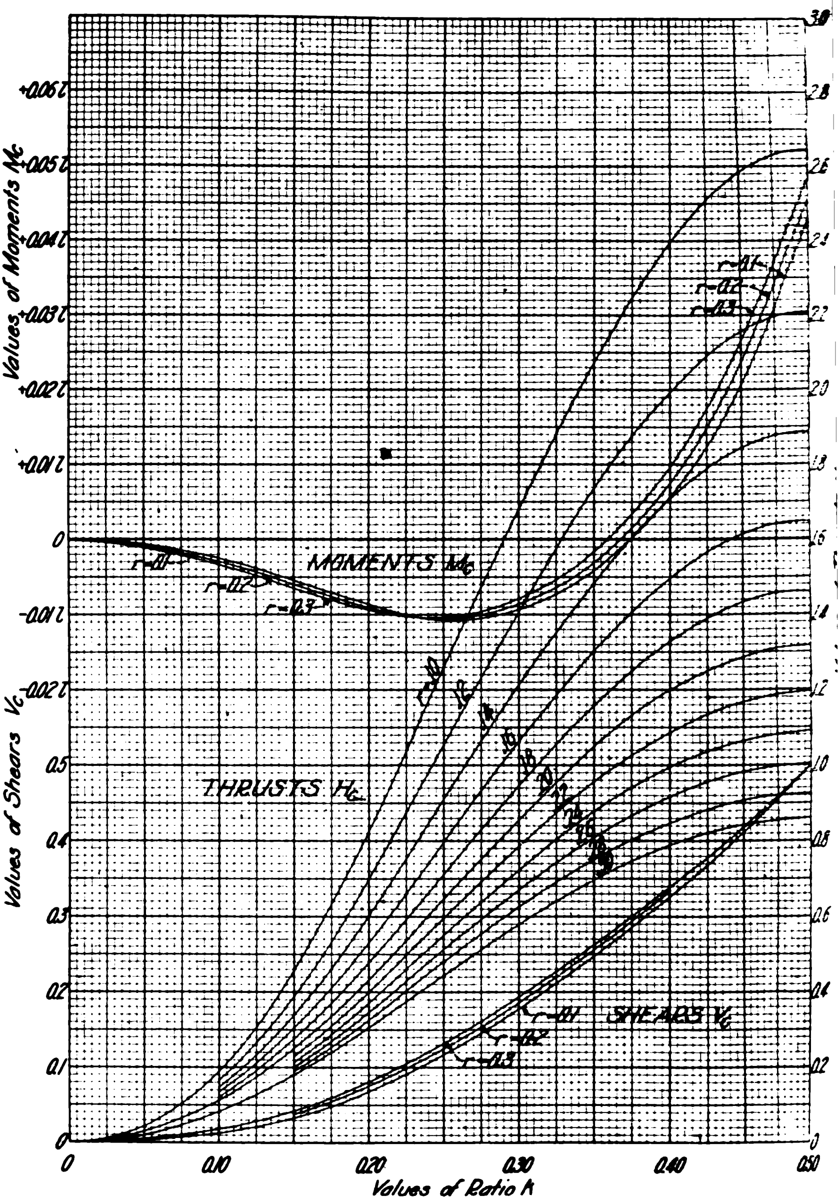


Fig. 8. Influence Lines for Moments, Thrusts and Shears at Crown; Open Spandrel Arch, Type A

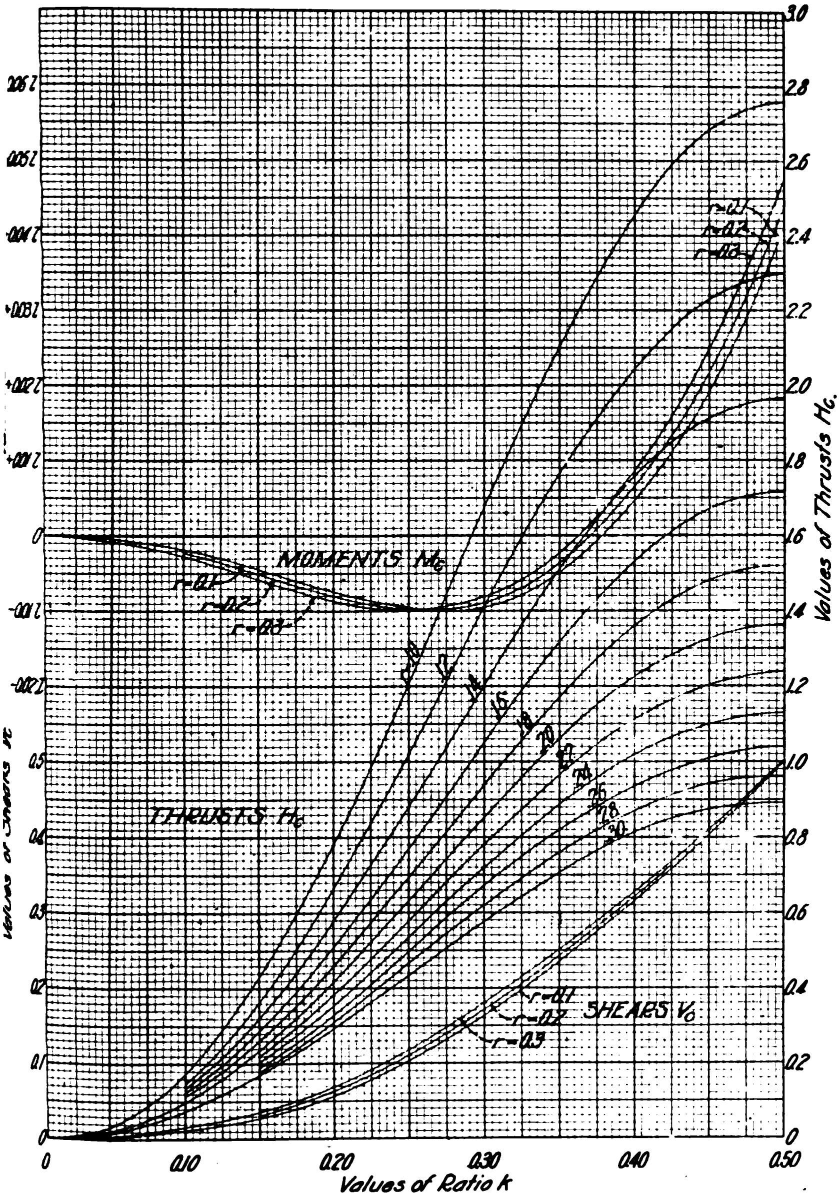


Fig. 9. Influence Lines for Moments, Thrusts and Shears at Crown; Open Spandrel Arch, Type $A_{2.5}$.

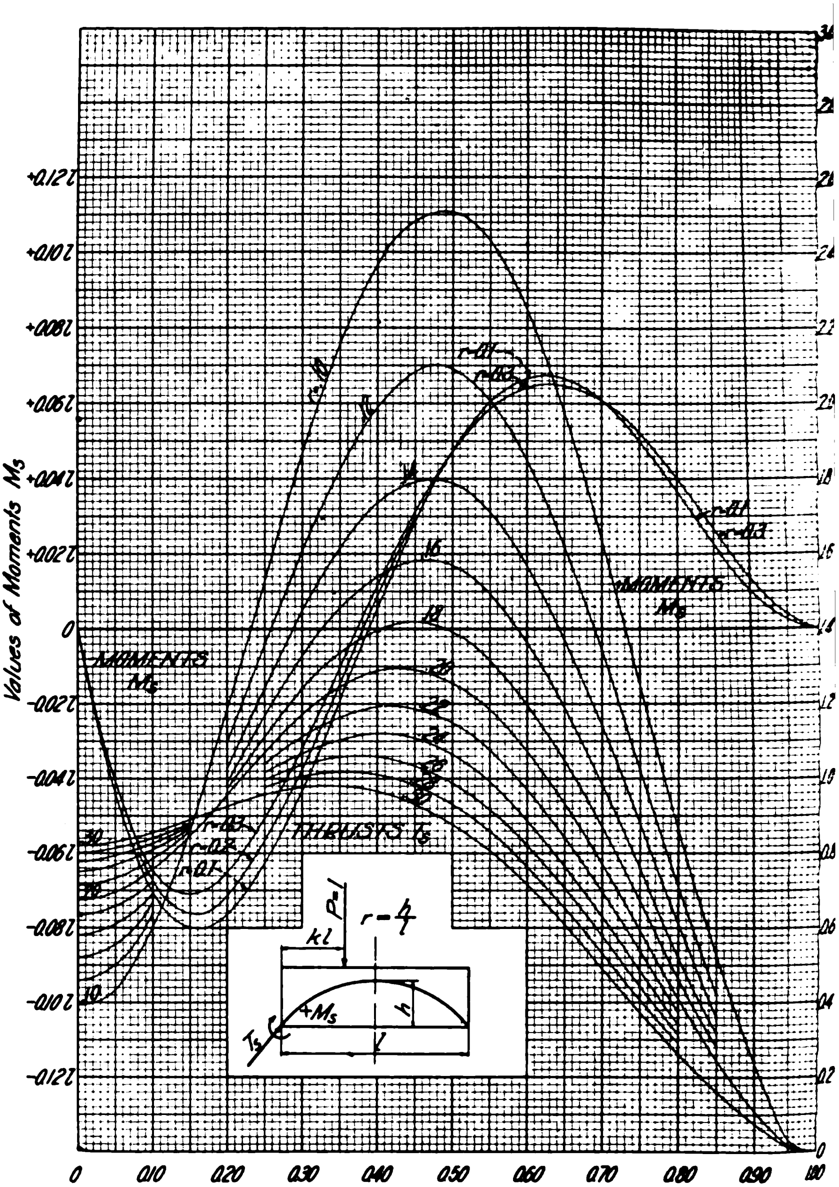


Fig. 10. Influence Lines for Moments and Thrusts at Springing; Open Spandrel Arch, Type $A_{T.S}$.

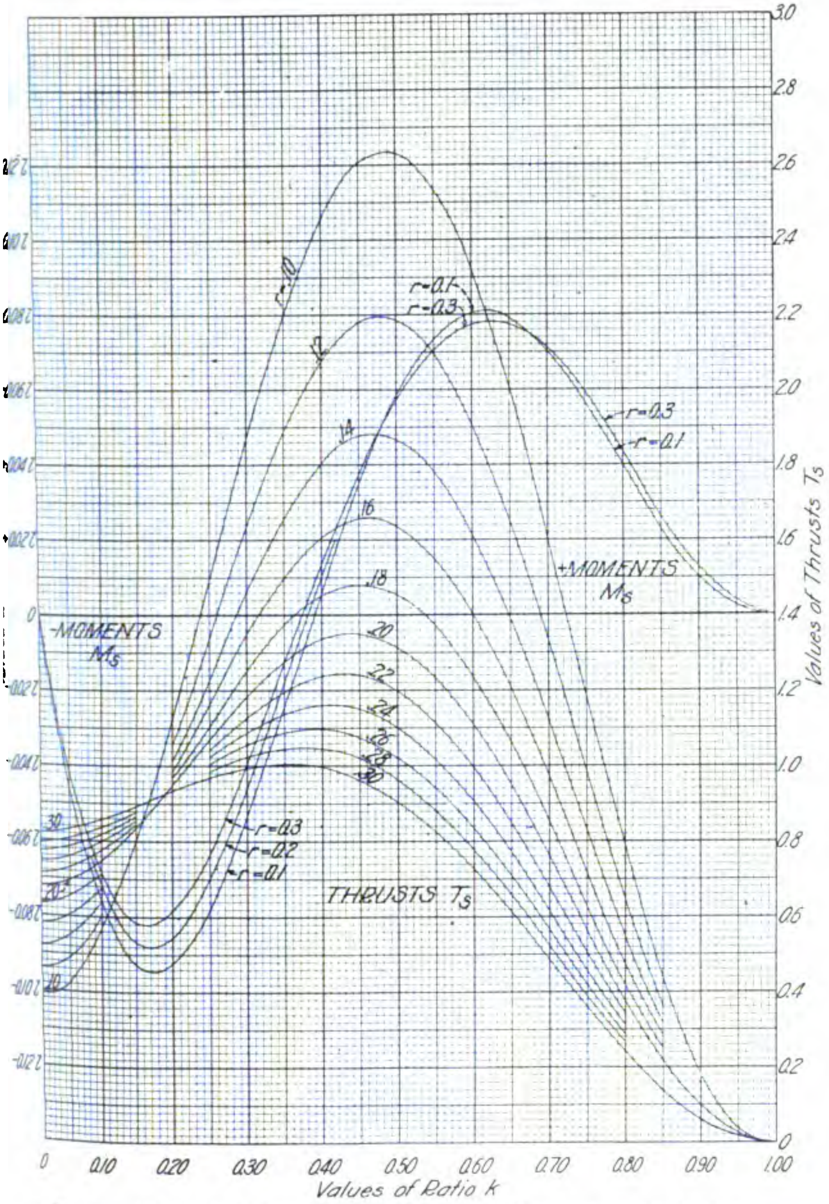


Fig. 11. **Influence Lines for Moments and Thrusts at Springing; Open Spandrel Arch, Type $A_{2,n}$.**

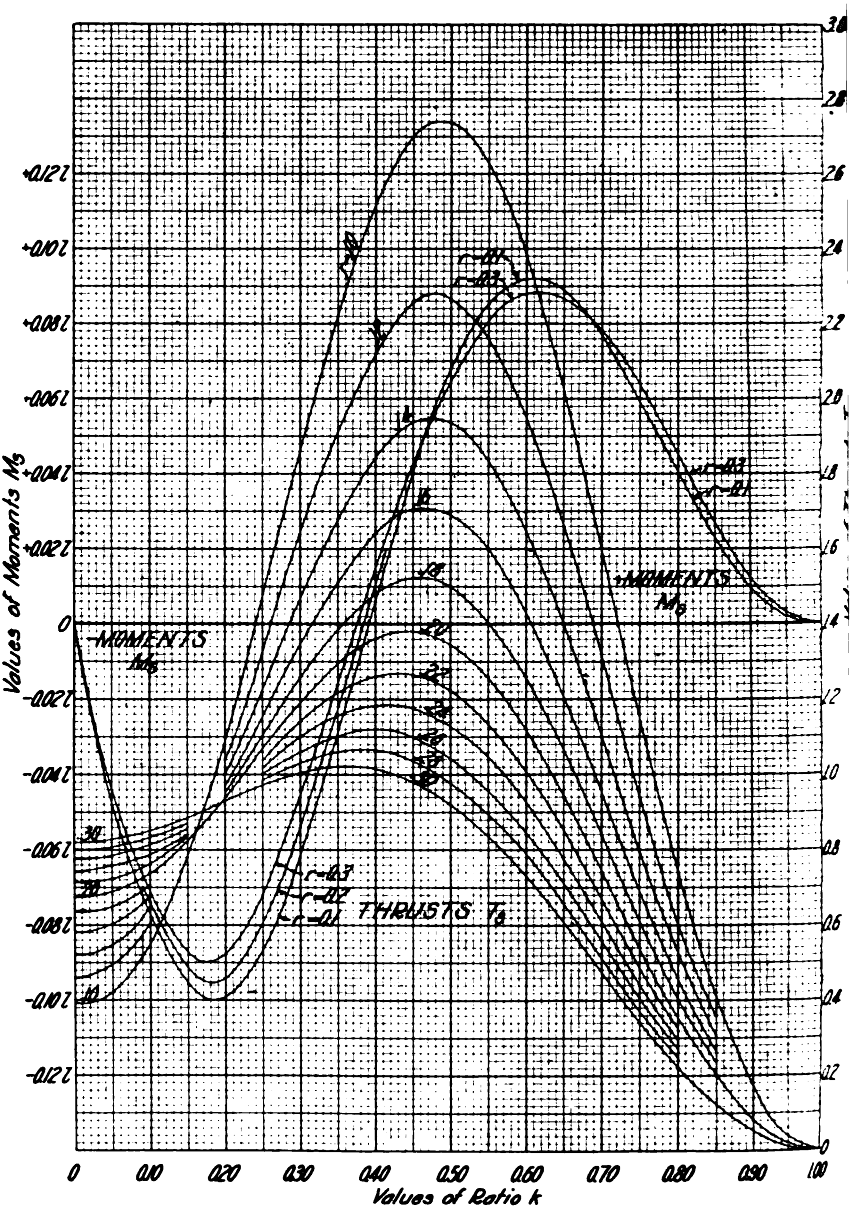


Fig. 12. Influence Lines for Moments and Thrusts at Springing; Open Spandrel Arch, Type $A_{3.5}$.

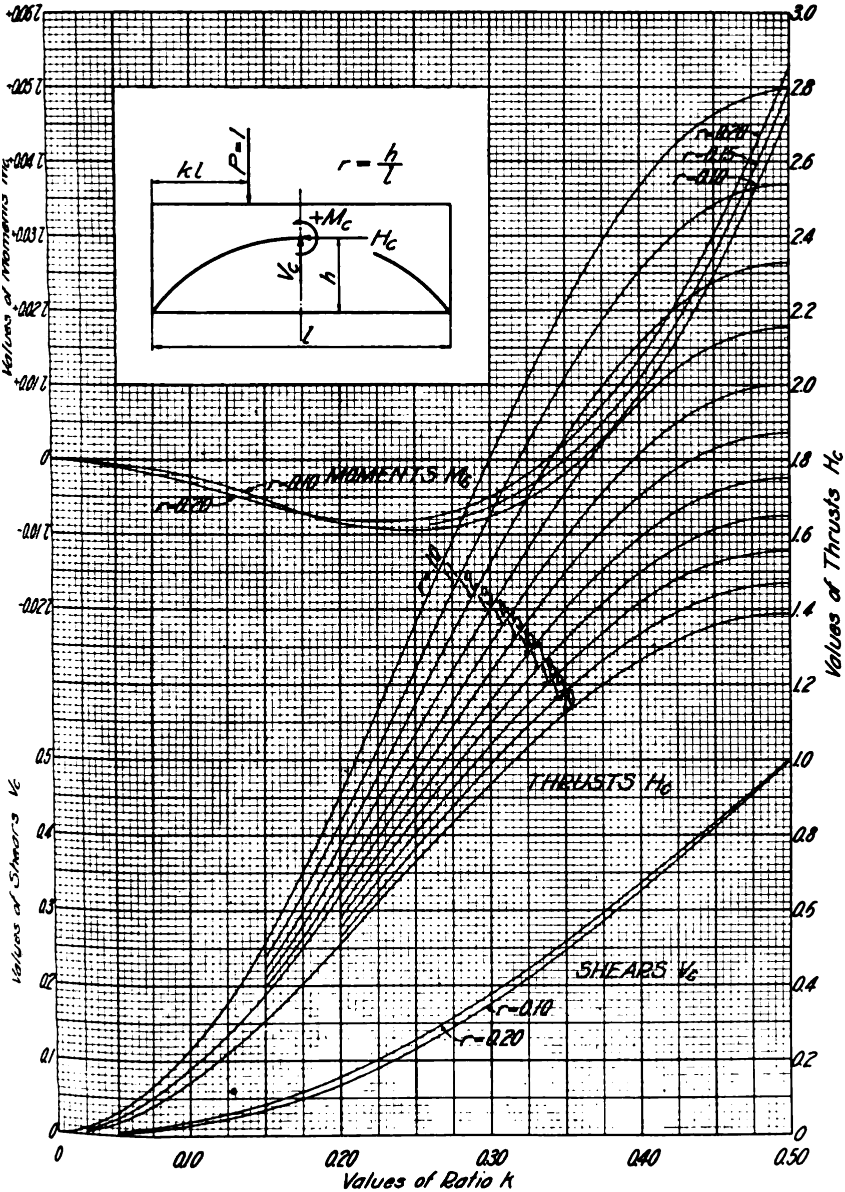


Fig. 13. Influence Lines for Moments, Thrusts and Shears at Crown; Filled Spandrel Arch, Type $A_{2.0}$.

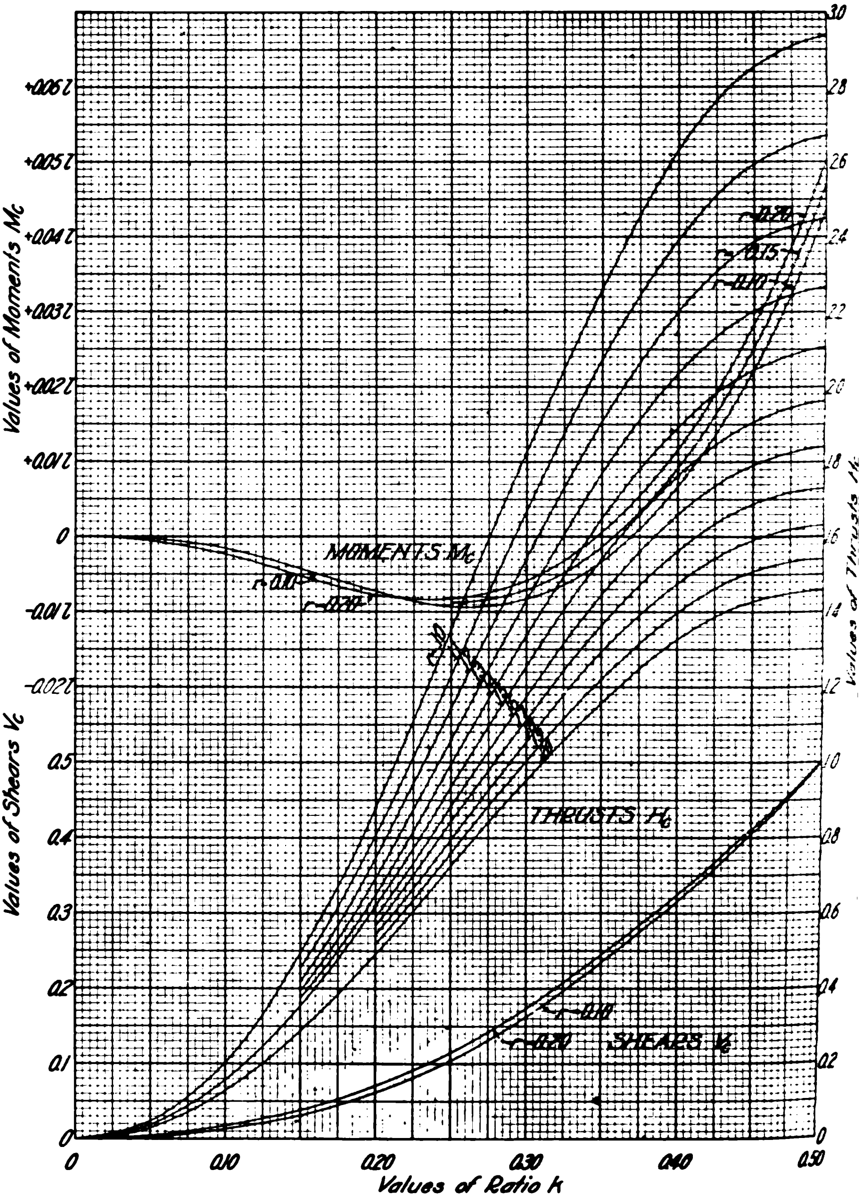


Fig. 14. Influence Lines for Moments, Thrusts and Shears at Crown; Filled Spandrel Arch, Type $A_{2.5}$.

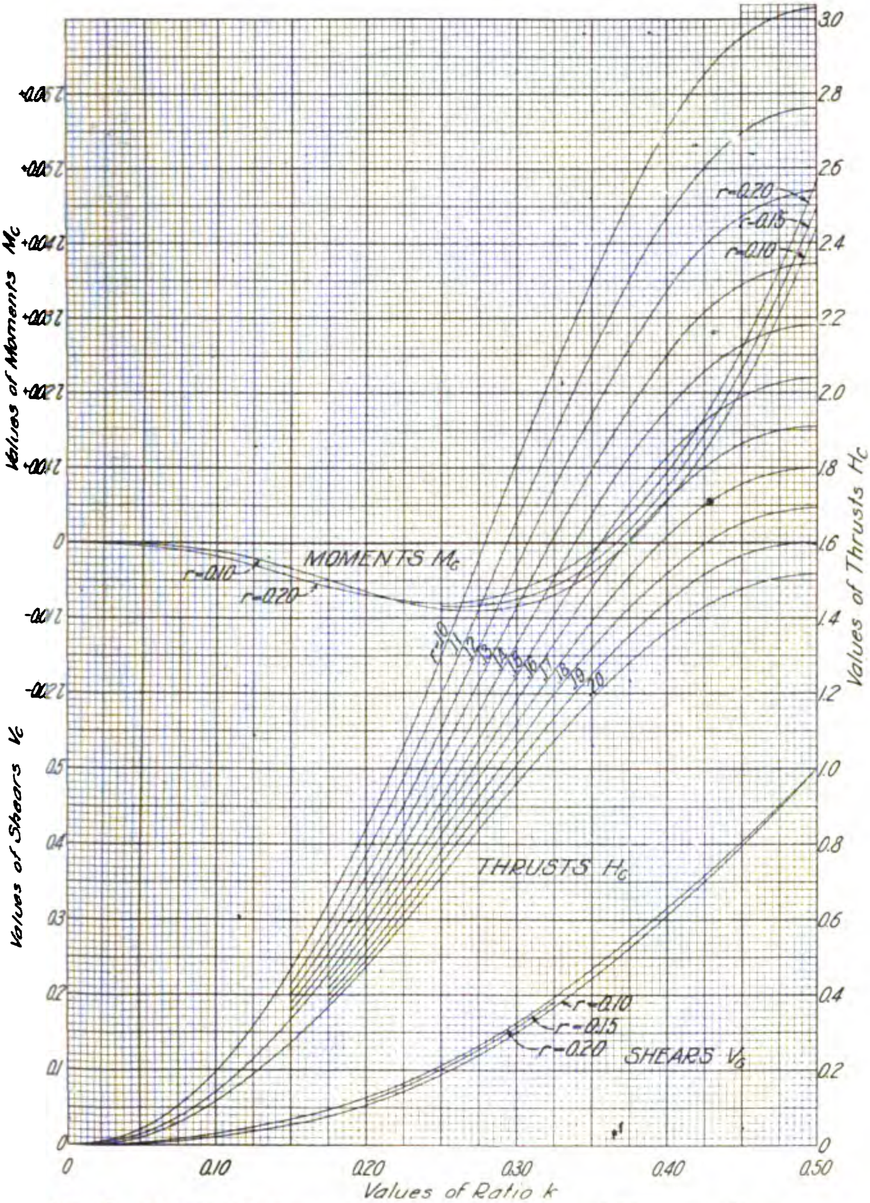


Fig. 15. Influence Lines for Moments, Thrusts and Shears at Crown; Filled Spandrel Arch, Type $A_{3,0}$.

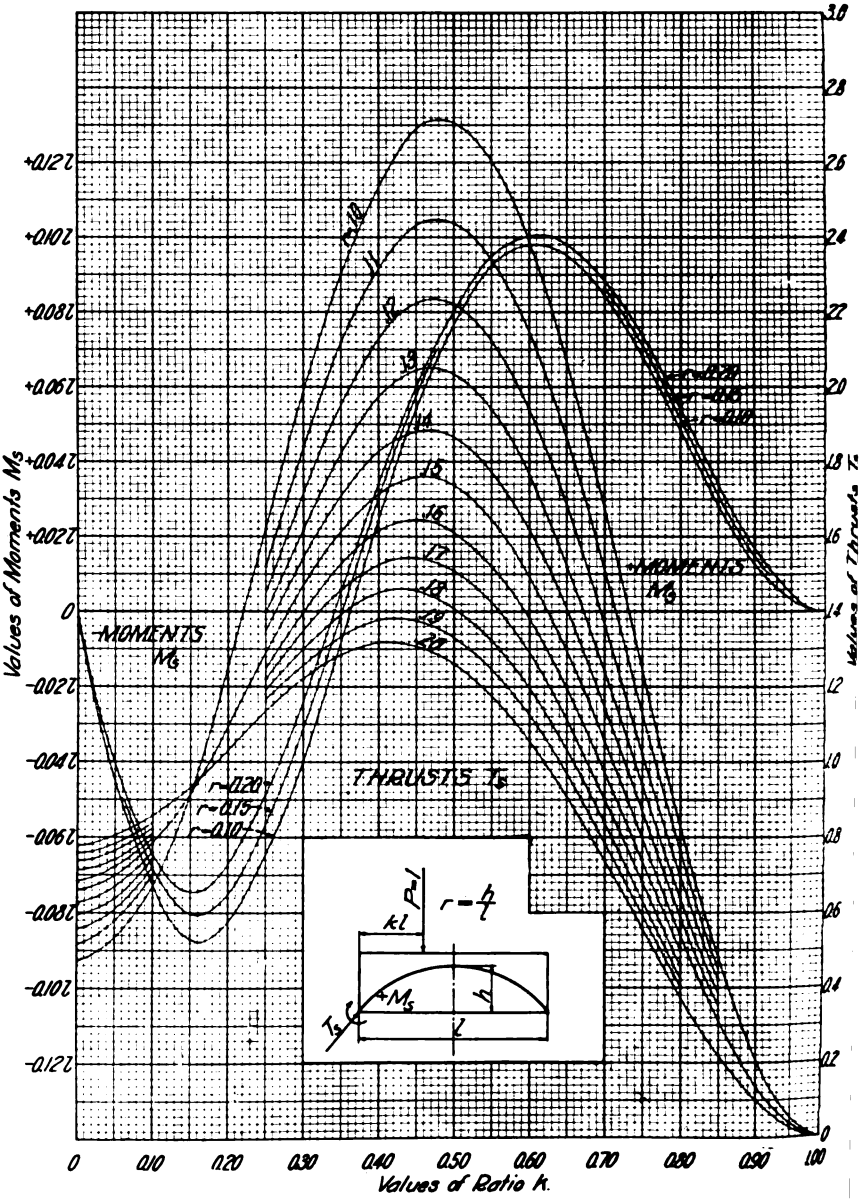


Fig. 16. Influence Lines for Moments and Thrusts at Springing; Filled Spandrel Arch, Type $A_{2.0}$.

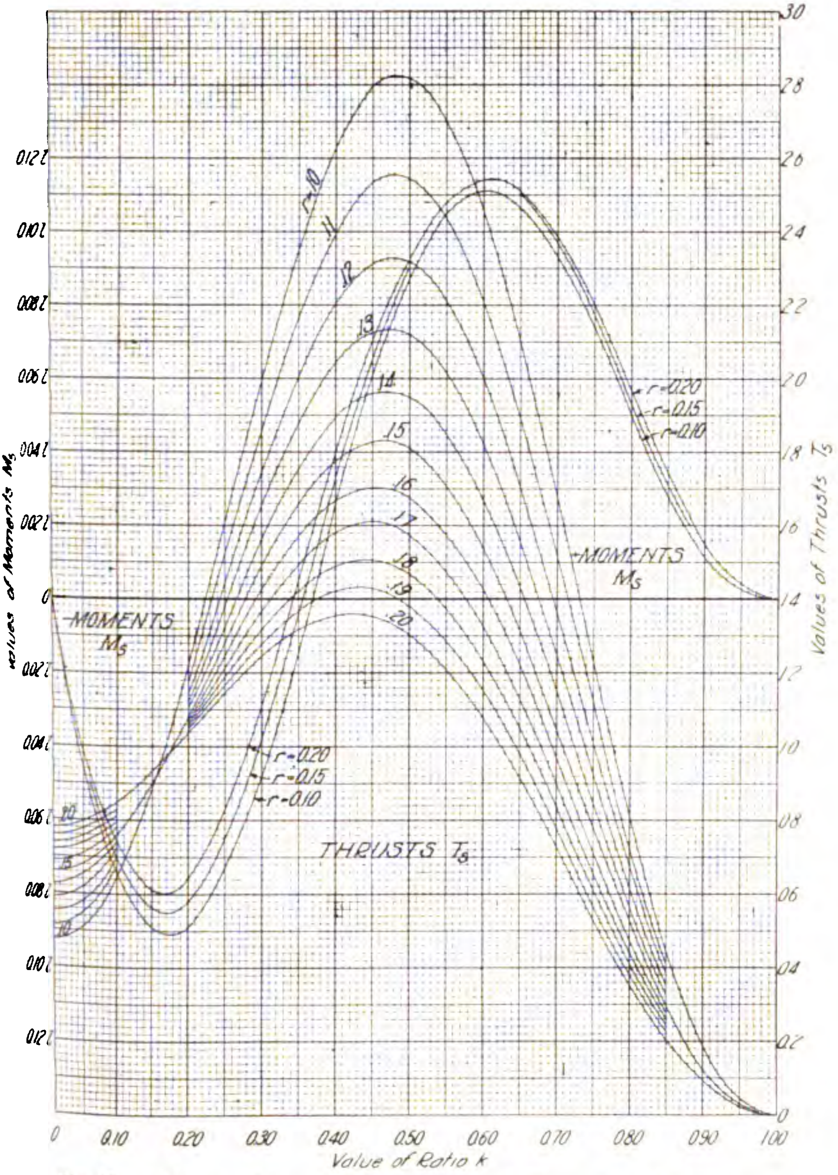


Fig. 17. Influence Lines for Moments and Thrusts at Springing; Filled Spandrel Arch, Type $A_{2.5}$.

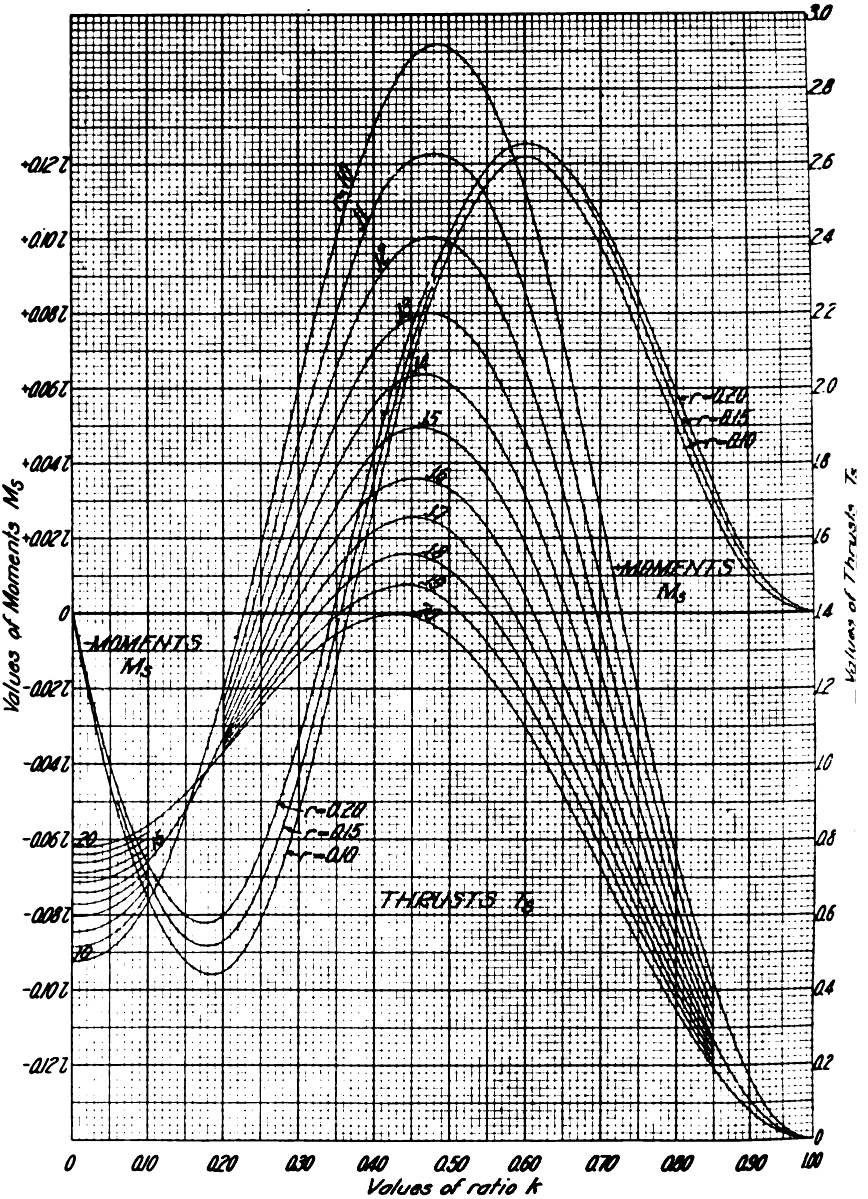


Fig. 18. Influence Lines for Moments and Thrusts at Springing; Filled Spandrel Arch, Type A $_{1.0}$.

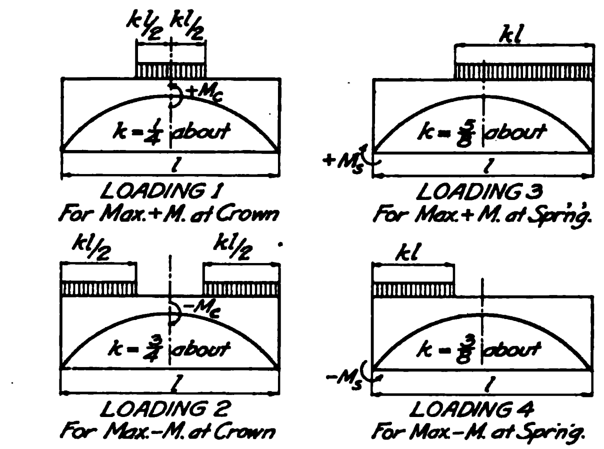


Fig. 19. Typical Loadings for Maximum Moments at Crown and Springing.

formulas below or otherwise the approximate actual or relative thicknesses at crown and springing, selects the typical arch best suited to the particular case, and reads from the diagrams, by interpolation if necessary, the values of the moments and thrusts at crown and springing. Having these values he constructs influence line diagrams to any desired scale and reads off from these the moments and thrusts due to the specified concentrated loads. If no concentrated loads are specified, or if uniform loads may be substituted for the concentrated loads, the influence lines are not needed and the formulas below are used instead. The influence diagrams are, therefore, of a more limited value than the formulas, but they are worthy of reproduction here because they bring out a number of points of especial interest, some of which will now be discussed.

It will be noted that the maximum live load moments at the crown and springing sections are determined by four typical arrangements of the live load, designated in Fig. 19 as Loadings *1*, *2*, *3* and *4*. Loadings *1* and *2* are for the maximum positive and negative moments at the crown, respectively, and when combined cover the entire span. Loadings *3* and *4* are for the maximum positive and negative moments at the springing section, respectively, and when combined likewise cover the span. In the figure, *k* represents the ratio of the length loaded to the span length. Loadings *1*, *3* and *4* are continuous, while Loading *2* is discontinuous.

An inspection of the moment diagrams reveals an unexpectedly small variation in the value of the ratio *k* for each loading, the variation being greater with respect to the rise than with respect to the type of arch. The following values of *k* are noted:

TABLE V.

RATIOS OF LOADED LENGTH TO SPAN LENGTH FOR LOADINGS PRODUCING MAXIMUM MOMENTS AT CROWN AND SPRINGING.

	Values of *k* for Open Spandrel Arches.	Values of *k* for Filled Spandrel Arches.
Loading 1	0.24 to 0.30	0.24 to 0.32
" 2	0.76 to 0.70	0.76 to 0.68
" 3	0.61 to 0.63	0.63 to 0.66
" 4	0.39 to 0.37	0.37 to 0.34

Hence it appears that, using approximate average values for *k*, the maximum positive moment at the crown occurs when the live load covers one-fourth of the span at the middle, and the maximum negative moment occurs when the load covers the two end three-eighths. The maximum positive moment at the springing is produced by a load covering five-eighths of the span beginning at the opposite end, and the maximum negative moment occurs when the load covers the adjacent end three-eighths of the span. It may be stated further that Loading *1* and Loading *4* combined produce Loading *3*, and that one-half of Loading *2* is the same as Loading *4*.

Another striking fact is that for any given type of arch the co-efficients for moments vary only slightly with respect to the rise-ratio. Hence we may say that the moments for any typical arch of given span length are practically independent of the rise-ratio.

As the ratio of springing thickness to crown thickness increases, the arch axis remaining the same, the moments at the springing increase and the moments at the crown decrease, as might be expected. The change in the moments as the arch axis changes in form, the ratio u_s remaining the same, may be seen by comparing the diagrams for an open spandrel arch with those for a filled spandrel arch having the same ratio u_s. Table VI presents a typical case. The positive moments at crown and springing increase as the arch axis departs farther from the parabolic form and becomes more nearly elliptical, while the negative moments at crown and springing decrease.

Evidently the areas enclosed by a moment influence line above and below the line of zero moments are a measure of the maximum moments due to a uniform live load on the span. The algebraic sum of the positive and negative areas is a co-efficient of the moments due to live load over the entire span. It is evident, therefore, from an inspection of the diagrams that the moments for live load over the whole span are generally much smaller numerically than the maximum moments, and are always positive at crown and springing.

Another interesting fact is that for arches of the same type (that is, having the same ratio u_s), but having axes of different form, the arithmetical sum of the positive and negative moments is practically the same. For example, take an open spandrel and a filled spandrel arch of the same rise-ratio $r = 0.2$ and the same thickness-ratio $u_s = 2.5$ (Figs. 9, 12, 14 and 17), and the moments are as follows:

TABLE VI.

COMPARISON OF MOMENTS FOR TYPE $A_{2.5}$ OPEN SPANDREL AND FILLED SPANDREL ARCHES. $(r=0.20)$

Section	Kind of Moment	Open Spandrel Arch	Filled Spandrel Arch
Crown	Max. + moment......	$+0.00474\,wl^2$	$+0.00637\,wl^2$
	" — "	$-0.00378\,wl^2$	$-0.00302\,wl^2$
	Algebraic sum........	$+0.00096\,wl^2$	$+0.00335\,wl^2$
	Arithmetical sum.....	$0.00852\,wl^2$	$0.00939\,wl^2$
Springing.	Max. + moment.....	$+0.02990\,wl^2$	$+0.04110\,wl^2$
	" — "	$-0.02330\,wl^2$	$-0.01750\,wl^2$
	Algebraic sum........	$+0.00660\,wl^2$	$+0.02360\,wl^2$
	Arithmetical sum.....	$0.05320\,wl^2$	$0.05860\,wl^2$

Thus while the maximum positive moments are more than one-third greater for the filled spandrel arch than for the open spandrel one, the arithmetical sums of the moments are only one-tenth greater. These two arch axes differ widely, and hence for two axes differing but little we may assume that the arithmetical sum of the maximum positive and negative moments is the same for each arch. This fact leads to an easily applied approximate method for correcting the known moments for an assumed axis to suit an actual arch having its axis differing in form from the assumed axis. This method is explained below.

If the arch axis is determined by dead load plus half live load, the effect of the dead load moments is to make the maximum positive and negative moments numerically equal (neglecting arch shortening). Hence in such a case the maximum moments due to live and dead loads are equal to half the arithmetical sum of the live load moments as determined by the influence lines. Hence it follows that for two arches of the same rise, span and thickness, but with axes somewhat different in shape but determined in each case by dead load plus half live load, the maximum positive and negative moments due to dead load and live load combined are approximately the same, if the live load is the same.

The moments in any typical arch due to *unit* loads are proportional to the span length, while the thrusts are the same for all span lengths. The shears at the crown are nearly independent of the rise and are the same for all span lengths. The thrusts at the crown increase as u_s increases and also as the arch axis approaches an elliptical form, and vary approximately inversely as the rise-ratio r.

PART V

FORMULAS FOR MOMENTS, THRUSTS AND AVERAGE STRESSES

The values of the maximum live load moments and the corresponding thrusts, in terms of wl^2 and wl, respectively, were computed from the influence line diagrams and plotted on cross-section paper. The thrusts and moments due to temperature variations were also calculated and plotted. It was found practicable to write general formulas for all these data, thus reducing them to small compass.

Since for any typical arch the relative areas are known, it is easy to compute the relative stresses at various sections due to the thrusts produced by any given loading, thus enabling the average direct stress throughout the arch to be calculated in terms of the stress at any particular section, such as that at the crown. In this

PLATE I.

TABLE OF FORMULAS FOR THRUSTS AND MOMENTS AT CROWN AND SPRINGING SECTIONS OF ARCHES

OPEN SPANDREL ARCHES

STRESSES PRODUCED BY	SECTION AT CROWN		SECTION AT SPRINGING	
DEAD LOAD (Approximate only: to be corrected)	$T_c = \frac{6+5r}{48r} w_c l$ M_c assumed = 0	(14)	$V_s = \frac{3+5r}{6} w_c l$ ······ (13) $T_s = \sqrt{T_c^2 + V_s^2}$ ········ M_s assumed = 0	(24)
LIVE LOAD MAXIMUM POSITIVE MOMENT	$T_c = \frac{59.5+31.5r+5r^2}{1000r} wl$ $M_c = +\frac{67.5+80r+40r^2-(20+13r)u_s+3u_s^2}{10000} wl^2$	(25) (26)	$T_s = \frac{93.3-42.5r+155r^2}{1000r} wl$ $T_c = \left(\frac{1}{2}T_{m2}+T_{m1}-\frac{0.0062}{u_s r}\right) wl$ $M_s = +\frac{322+27r-(18.1+13r)(3.79-0.6r-u_s)^2}{10000} wl^2$	(27) (28) (29)
LIVE LOAD MAXIMUM NEGATIVE MOMENT	$T_c = \frac{61+2u_s+(7+2u_s)r-70r^2}{1000r} wl$ $M_c = -\frac{55-9u_s+0.85u_s^2}{10000} wl^2$	(30) (31)	$T_s = \frac{24.4+(211-2u_s)r+(120+80u_s)r^2}{1000r} wl$ $T_c = \left(\frac{1}{2}T_{m2}+\frac{0.0062}{u_s r}\right) wl$ $M_s = -\frac{289-172r-(17.8-26r)(3.96+2.4r-u_s)^2}{10000} wl^2$	(32) (33) (34)
TEMPERATURE (FALL OF t°)	$T_c = -\left[18.4u_s-7.5-(20.5u_s-15)r-(10u_s-2)r^2\right]\frac{\omega t E_c I_0}{h^2}$ $M_c = -\left[46.25-17.5u_s+2.44u_s^2+5r+(25.5-36u_s)r^2\right]\frac{hT_c}{100}$	(35) (36)	$T_s = (1.09-1.75r)T_c$ $M_s = M_c + hT_c$	(37) (38)

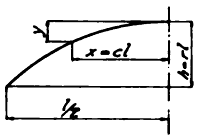
FILLED SPANDREL ARCHES

STRESSES PRODUCED BY	SECTION AT CROWN		SECTION AT SPRINGING	
DEAD LOAD (Approximate only: to be corrected)	$T_c = \frac{1+3r}{8r} w_c l$ M_c assumed = 0	(17)	$V_s = \frac{2+15r}{4} w_c l$ ···· (16) $T_s = \sqrt{T_c^2 + V_s^2}$ ········ M_s assumed = 0	(39)
LIVE LOAD MAXIMUM POSITIVE MOMENT	$T_c = \frac{57.6+(189-8u_s)r-220r^2}{1000r} wl$ $M_c = +\frac{72+105r+220r^2-(17+10r)u_s+1.5u_s^2}{10000} wl^2$	(40) (41)	$T_s = \frac{84+6.6u_s+(153-51u_s)r-(500-140u_s)r^2}{1000r} wl$ $T_c = \left[\frac{1}{2}T_{m2}+T_{m1}+\frac{0.0026(u_s-2)^2}{r}\right] wl$ $M_s = +\frac{316+1370r-2100r^2-(17-20r)(3.60+7.6r-u_s)^2}{10000} wl^2$	(42) (43) (44)
LIVE LOAD MAXIMUM NEGATIVE MOMENT	$T_c = \frac{57.8+2u_s+(10+30u_s)r-(380+30u_s)r^2}{1000r} wl$ $M_c = -\frac{49.4-100r-(3-26r)u_s-0.75u_s^2}{10000} wl^2$	(45) (46)	$T_s = \frac{27.6+(125+6u_s)r+320r^2}{1000r} wl$ $T_c = \left[\frac{1}{2}T_{m2}-\frac{0.0026(u_s-2)^2}{r}\right] wl$ $M_s = -\frac{283-480r-9(4.22-2.8r-u_s)^2}{10000} wl^2$	(47) (48) (49)
TEMPERATURE (FALL OF t°)	$T_c = -\left[19.4u_s-7.5+(17u_s-31)r-140(u_s-1)r^2\right]\frac{\omega t E I_0}{h^2}$ $M_c = -(38.5-12.8u_s+1.6u_s^2)\frac{hT_c}{100}$	(50) (51)	$T_s = (1.13-2.55r)T_c$ $M_s = M_c + hT_c$	(52) (53)

AVERAGE STRESSES

FOR DEAD LOAD	$f_a = \left[1.030+2.5(r+0.05)^2-\frac{(20r+8)u_s-(u_s-1)^2}{100}\right]f_{ac}$	(54)
FOR LIVE LOAD PRODUCING MAX. POS. MOMENT AT CROWN	$f_a = \left[0.920+2.6r^3-0.04u_s+\frac{(6.7+33r)(4-u_s)^2}{1000}\right]f_{ac}$	(55)
FOR LIVE LOAD PRODUCING MAX. NEG. MOMENT AT CROWN	$f_a = \left[0.840+1.1(r+0.1)^2-0.055u_s+\frac{(6+156r^3)(4-u_s)^2}{1000}\right]f_{ac}$	(56)
FOR LIVE LOAD PRODUCING MAX. POS. MOMENT AT SPRINGING	$f_a = \left[0.920+3.7r^3-0.04u_s+\frac{(7.5+37r)(4-u_s)^2}{1000}\right]f_{ac}$	(57)
FOR LIVE LOAD PRODUCING MAX. NEG. MOMENT AT SPRINGING	$f_a = \left[0.950+1.7r^2-0.05u_s+\frac{(4+48r)(4-u_s)^2}{1000}\right]f_{ac}$	(58)
FOR TEMPERATURE AND ARCH SHORTENING STRESSES	$f_a = \left[1.075-0.8r-(0.081-0.11r)u_s\right]f_{ac}$	(59)

These formulas are for arches having axes as determined by the following equations:



For Open Spandrel Arches:

$$y = \frac{8rl}{6+5r}(3c^2+10c^4r) \qquad (12)$$

For Filled Spandrel Arches:

$$y = \frac{4rl}{1+3r}(c^2+24c^5r) \qquad (15)$$

Plate No. 1. Formulas for Thrusts and Moments.

way formulas were obtained for average direct stresses, for use in computing the effect of the arch shortening.

The formulas are given on Plate I. The notation used is as follows:

l = the span length of the arch axis in feet.
h = the rise of arch axis in feet.
r = the rise-ratio h/l.
y = the ordinate of the arch axis at any point the abscissa of which is cl.
u_s = ratio of the thickness at springing to the thickness at crown.
M_c = moment at crown in foot lbs.
T_c = thrust at crown in pounds.
M_s = moment at springing in foot lbs.
T_s = thrust at springing in lbs.
T_{m1} = coefficient of wl for thrust at crown corresponding to maximum positive moment at crown (Loading 1).
T_{m2} = coefficient of wl for thrust at crown corresponding to maximum negative moment at crown (Loading 2).
V_s = approximate dead load vertical end reaction, or one half dead weight of span in pounds.
w_c = weight of arch at the crown, plus average weight of arch superstructure at the crown, in lbs. per lineal foot of span.
w = live load in lbs. per lineal foot of span (not necessarily the same for all positions of the live load).
ω = the coefficient of linear expansion due to temperature changes.
t = change in temperature in degrees F.
E = modulus of elasticity of concrete in lbs. per sq. ft.
I_0 = the moment of inertia of the arch rib at the crown in ft.^{4}.
f_a = average direct stress throughout arch in lbs. per sq. ft.
f_{ac} = direct stress at crown section in lbs. per sq. ft.

From what has been said the use of these formulas will be readily understood. Following is a summary of the steps required in designing an arch by the use of the formulas. It is assumed that the arch superstructure has been designed, and that the dead load per lineal foot at the crown, exclusive of the arch rib, is known; also that the span and rise of the axis have been fixed.

1. Assume a crown thickness in accordance with one of the empirical formulas in use, or by comparison with a previous design, and compute the total dead load per lin. ft. of span at the crown ($= w_c$).

2. Assume the arch type, or the thickness-ratio u_s. For open spandrel arches this ratio will usually be from 1.5 to 2.5, and for filled spandrel arches from 2 to 3.25.

3. Compute the dead load thrusts and the maximum positive and negative moments and corresponding thrusts at the crown and springing due to live load, temperature variation and arch shortening, and calculate the extreme fiber stresses due to the proper combinations of moments and thrusts. If the stresses so found are too great or too small change the thickness at the crown or at the springing, or both, and repeat the above operation. The second trial will usually be sufficient. If the thicknesses originally assumed are not correct the fact will usually be revealed before the first set of calculations are completed.

4. Lay out the assumed arch axis as per formula (12) or formula (15) and divide it into 10 or more equal parts, locating the center of each division. At the points thus found lay off the half thickness as given in Fig. 5 or in Table I, above and below the assumed axis, and through the points thus determined pass, as nearly as practicable through all the points, segmental, three-centered, or five-centered curves. A set of railroad curves is useful for this purpose.

5. Compute the dead loads at the panel points or at suitable intervals and lay out an equilibrium polygon passing through the crown and springing, the value of the horizontal thrust being first computed as for a three-hinged arch and used as the pole distance for the force polygon.

6. By trial alter the shape of the arch axis so that it will fit the dead load equilibrium polygon as nearly as practicable, lay out the arch thicknesses again, and determine the radii of the intradosal and extradosal curves.

7. If the actual axis departs considerably from the assumed axis scale the dead load thrusts from the force polygon and correct the maximum live load moments by the method given below, revising the stresses and changing the thicknesses if necessary. This last step will seldom be required.

PART VI

APPROXIMATE METHOD OF CORRECTING MAXIMUM MOMENTS IN CASE THE ACTUAL ARCH AXIS DEVIATES FROM THE ASSUMED AXIS

One of the three fundamental equations of condition is as follows:

$$\int \frac{Mds}{EI} = 0.$$

Now if the arch axis is divided into a sufficient number of sections of length Δs so that the ratio

$$\frac{\Delta s}{I}$$

is constant, we may write, assuming that E is constant,

$$\Sigma M = 0.$$

Let i = the vertical intercept between the arch axis and the resistance line. Then $M = Hi$, where H is the horizontal thrust, and, since H is constant,

$$\Sigma i = 0.$$

That is, the algebraic sum of the intercepts between the arch axis and the resistance line at the division points is equal to zero. This rule gives a means of quickly checking the correctness of the graphical construction of the resistance line in any case.

On account of this law it is found that for any given typical arch, that is, for an arch having a constant ratio u_s, the resistance line for live load over the entire span crosses the arch axis at about the same horizontal distance from the center line of the span, regardless of the shape of the arch axis. For example, in Fig. 20 the line *CABS* represents the axis of an open spandrel arch of type $A_{2.5}$ and rise ratio = 0.2, while *CDES* represents the axis of a type $A_{2.5}$ filled spandrel arch. The vertical scale is 3-1/3 times the horizontal. The resistance lines for full live load are *MABN* and *ODEP*, respectively, and it will be seen that the intersection points *A* and *D* are about equidistant from the center line, as are also *B* and *E*. It appears, then, that if the full load resistance line for one axis, as *CABS*, is known, the resistance line for another axis, as *CDES*, may be approximately determined by passing the parabola *ODEP* through the two points

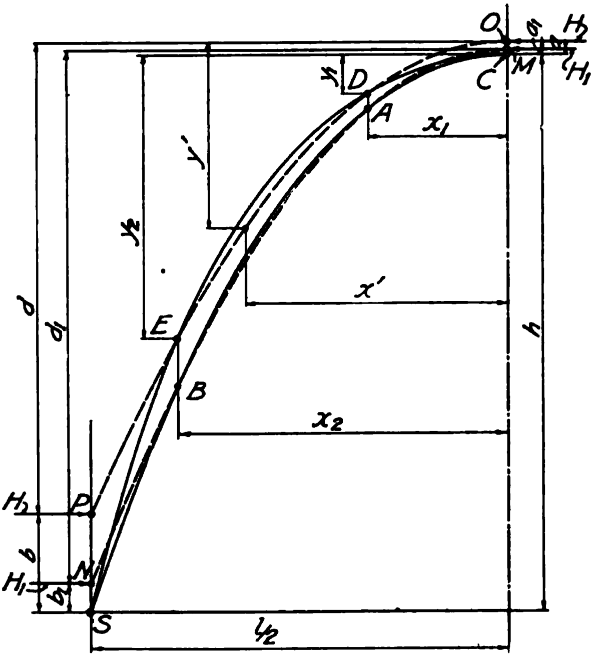


Fig. 20. Resistance Lines for an Open Spandrel and a Filled Spandrel Arch, Live Load Over Whole Span.

D and *E* having the abscissas x_1 and x_2 the same as for the known intersection points *A* and *B*, and the ordinates y_1 and y_2, referred to *C* as origin.

Let d = the rise of the required parabolic resistance line for live load over the entire span.

a = the vertical intercept between the arch axis and the required resistance line at the crown.

b = the vertical intercept at the springing.

d_1, a_1 and b_1 = the corresponding known terms for the assumed arch.

The equation of the resistance line *ODEP* referred to *O* as origin is $y' = kx'^2$, k being a constant. Transferring the origin to *C*, the equation becomes:

$$y + a = kx^2$$

Then $y_1 + a = kx_1^2$

and $y_2 + a = kx_2^2$

Whence $k = \dfrac{y_2 - y_1}{x_2^2 - x_1^2}$ . . . . (60)

Then we have

$a = kx_1^2 - y_1$ . . . . (61)

$d = \dfrac{kl^2}{4}$ . . . . (62)

and $b = h + a - d$ . . . . (63)

Let M'_p = the known maximum positive moment at crown or springing for the assumed axis $CABS$.

M'_n = the known maximum negative moment at crown or springing for the assumed axis $CABS$.

M_1 = the known moment due to live load over the whole span.

$= M'_p + M'_n$

S_1 = the arithmetical sum of the moments M'_p and M'_n

$= M'_p - M'_n$

H_1 = the horizontal thrust for the known resistance line $MABN$.

Also let M_p, M_n, M, S, and H be the corresponding terms for the actual axis $CDES$ (or resistance line $ODEP$).

It is evident that

$$M'_p = \frac{M_1 + S_1}{2}$$

and $$M'_n = \frac{M_1 - S_1}{2}$$

and similarly, that

$$M_p = \frac{M + S}{2}$$

and $$M_n = \frac{M - S}{2}$$

It was shown above that for practical purposes we may assume that the arithmetical sum of the moments is constant. Hence substituting S_1 for S in the last two equations we get

$$M_p = \frac{M + S_1}{2}$$

and $$M_n = \frac{M - S_1}{2}$$

At the crown $M = Ha$, hence, noting that $H = \dfrac{H_1 d_1}{d}$, we get the following formulas for the crown moments:

$$M_p = \frac{H_1 a \frac{d_1}{d} + S_1}{2} \qquad (64)$$

$$M_n = \frac{H_1 a \frac{d_1}{d} - S_1}{2} \qquad (65)$$

For the springing moments substitute *b* for *a* in the above formulas.

These formulas will give close approximations to the true values of the moments even if the axis used deviates considerably from the assumed axis.

PART VII

EXAMPLES SHOWING THE USE OF THE FORMULAS AND DIAGRAMS

The writer has tested the reliability of the influence line diagrams and the formulas in the case of a considerable number of actual designs, by comparing the results obtained by their use with the data given by the designers. In some cases there was a considerable difference between the two sets of values, due to the fact that the arch axis departed considerably from the dead load equilibrium polygon through the centers of crown and springing or to the fact that the haunch thickness was greater than necessary in comparison with the crown thickness. In all such cases, however, the values obtained by the diagrams and formulas were close enough to the true values for practical purposes, except in the case of the temperature and arch shortening effects. It seems, too, that in most cases where a considerable difference was found in the results, the design might have been improved slightly in one or both of the particulars mentioned above.

A number of examples will now be given showing the application of the diagrams and formulas, and also indicating the degree of approximation to be expected in case the conditions are not in agreement with the assumptions made in developing the diagrams and formulas.

Example 1. A 100 ft. open spandrel arch in Turneaure and Maurer's "Principles of Reinforced Concrete Construction," 2nd ed., p. 357.

In this case we have:

$l = 100$

$h = 20 \therefore r = 0.20$

$t_0 = 2.5$

t_s (thickness at springing) $= 3.5$

$\therefore u_s = 1.4$

The values of the thrusts, shears and moments at the crown may be taken from Fig. 7 ($u_s = 1.5$). The table gives the values so obtained and also the exact values.

k	H_c		V_c		M_c	
	As shown in Fig. 7	As given by T. & M.	As shown in Fig. 7	As given by T. & M.	As shown in Fig. 7	As given by T. & M
0.10	0.14	0.139	0.024	0.024	—0.38	—0.37
0.20	0.47	0.477	0.092	0.097	—1.00	—0.92
0.30	0.85	0.849	0.203	0.207	—0.82	—0.78
0.40	1.14	1.142	0.345	0.345	+0.95	+0.80
0.50	1.25	1.254	0.500	0.500	+4.75	+4.54

This arch is somewhat thicker in the haunch than necessary.

Example 2. A 100 ft. open spandrel arch, Hudson's "Deflections and Statically Indeterminate Stresses," pp. 96 and 97.

The following data are given:

$l = 100$

$h = 29 \therefore r = 0.29$

$t_0 = 2.25', t_s = 4.00' \therefore u_s = 1.78$

This arch is thicker in the haunch than necessary. The thickness at the quarter point might have been made about 20 percent less. The axis lies very close to the assumed axis, so the table shows the discrepancy due to the fact that the haunch thicknesses are greater than assumed for the typical arches. Diagrams for $u_s = 1.75$, from which the following values were read, are not given, but the values may be obtained approximately from Fig. 7 and Fig. 8 by interpolation.

	H_c		V_c		M_c	
k	As given by diagrams	As given by Hudson	As given by diagrams	As given by Hudson	As given by diagrams	As given by Hudson
0.025	0.	0.	0.	0.	0	0
0.075	0.050	0.050	0.011	0.011	—0.20	—0.17
0.125	0.140	0.137	0.030	0.032	—0.50	—0.43
0.175	0.260	0.252	0.065	0.064	—0.85	—0.68
0.225	0.395	0.385	0.110	0.106	—1.05	—0.87
0.275	0.530	0.525	0.168	0.158	—0.95	—0.88
0.325	0.655	0.659	0.232	0.221	—0.50	—0.59
0.375	0.760	0.775	0.305	0.293	+0.40	+0.11
0.425	0.835	0.861	0.381	0.373	+1.80	+1.34
0.475	0.870	0.906	0.460	0.457	+3.80	+3.18

For a rise of 50° in temperature the following values of the thrust and moments are given:

H_c = *2330 lbs.*
M_c = *14030 ft. lbs.*
M_s = *53540 ft. lbs.*

Substituting in formulas (35), (36) and (38), (Plate I),

$$H_c\ (or\ T_c) = \left[18.4\times1.78-7.5-(20.5\times1.78-15)\ 0.29-(10\times1.78-2)0.29^2\right]\frac{0.0000055\times50\times288000000\times0.95}{29\times29}$$

$$=1580$$

$$M_c = \frac{-25.8\times29\times1580}{100} = -11800$$

$$M_s = +34000$$

These results show the advantage of making the haunch thickness a minimum.

Example 3. A 132 ft. arch, Kansas River bridge at Lawrence, Kan. This is a rather flat open spandrel arch. Following are the dimensions:

$l = 132$
$h = 16\ \therefore\ r = 0.121$
$t_0 = 2.5$
$t_s = 5.63\ \therefore\ u_s = 2.25$

The table gives the values of the thrusts, shears and moments at the crown:

k	H_c		V_c	
	As given by diagrams	As computed by exact method	As given by diagrams	As computed by exact method
0.038	0.02	0.	0.	0.
0.080	0.09	0.050	0.008	0.005
0.122	0.24	0.200	0.020	0.019
0.164	0.45	0.419	0.040	0.040
0.206	0.71	0.680	0.070	0.070
0.248	1.01	0.970	0.110	0.109
0.290	1.32	1.272	0.160	0.157
0.332	1.61	1.564	0.215	0.213
0.374	1.86	1.822	0.280	0.278
0.416	2.07	2.028	0.350	0.348
0.458	2.19	2.149	0.423	0.423
0.500	2.23	2.191	0.500	0.500

k	M_c	
	As given by diagrams	As computed by exact method
0.038	—0.06	0
0.080	—0.22	—0.085
0.122	—0.47	—0.350
0.164	—0.81	—0.730
0.206	—1.12	—1.060
0.248	—1.29	—1.245
0.290	—1.25	—1.235
0.332	—0.86	—0.900
0.374	—0.08	—0.155
0.416	+1.29	+1.075
0.458	+3.10	+2.965
0.500	+5.68	+5.437

This arch will serve also to exemplify the use of the formulas. The complete calculations will now be given and the results will be compared with those obtained by the exact method. Typical half sections of the span are shown in Fig. 21.

The live loads are as follows:

LIVE LOADS

Member Loaded	Portion of Structure Loaded		
	Track	Remainder of Roadway (18 ft.)	Sidewalks
For roadway floor slabs, fascia-girders, cantilever beams, cross-girders, spandrel columns, and approach girder spans.	Electric Railway Loading, (Assumed to occupy a transverse width of 12 ft.)	20-ton Road Roller or 200 lbs. per sq. ft.	150 lbs. per sq. ft.
For arch rings and abutments.	Ditto	60 lbs. per sq. ft...	50 lbs. per sq. ft.
	Or the equivalent uniform loads given below.		
For the unbalanced load on piers.	3500 lbs. per lin. ft. span.	50 lbs. per sq. ft....	40 lbs. per sq. ft.

The wheel loads are shown in Fig. 22.

The working stresses assumed were as follows:

WORKING STRESSES IN LBS. PER SQ. IN.

Member	Kind of Stress	Stress
Floor slabs	Compression in concrete	600
	Tension in steel	16000
Arch Rings	Compression on concrete, including L.L., D.L., and rib shortening	600
	Compression on concrete, including L.L., D.L., rib shortening and temperature (for a variation of ± 40°)	800

$E_s = 30\,000\,000$ $E_c = 2\,000\,000$ $n = 15$

ω = Coefficient of expansion = 0.0000055

In order to employ the formulas it is necessary to use a uniform live load in lieu of the concentrated loads shown in Fig. 22 for the electric railway track. It is difficult, if not impracticable, to work out equivalent uniform loads for arches such as are in use for simple beam and truss spans. It will usually be sufficiently accurate for practical purposes to use the average weight per lineal foot of car. Hence we assume the uniform load as follows:

Average weight of car	$\frac{150,000}{43}$	= 3490
Uniform load on roadway	= (30–12)x60	= 1080
Uniform load on sidewalks	= 10x50	= 500
Total		5070 lbs.

Then we have $wl = 5070 \times 132 = 669,000$ lbs.

and $wl^2 = 5070 \times 132^2 = 88\,340\,000$ ft. lbs.

It will be assumed to begin with that rough preliminary calculations have been made from which it is found that the crown thickness t_0 may be assumed = 2.5, and the ratio u_s = 2.25. The first step is to compute the dead load per lineal foot at the crown (w_c), thus:

Weight of track, paving, and paving base on sand fill	4 000
Weight of concrete in floor slabs, fascia girders and side walls	3 170
Weight of cantilever brackets, per ft. of span	1 300
Weight of sand fill	2 880
Weight of railings	800
Weight in conduit spaces	250
Weight of arch rib, 24x2.5x150	9 000
Total w_c =	21,400 lbs.

Dead Load:

Substituting in formula (14), T_c (or H_c)

$$= \frac{(6 + 5 \times 0.121) \times 21400 \times 132}{48 \times 0.121}$$

$= 3\,210\,000$ lbs.

From formula (13), $V_s = \frac{3.605 \times 21400 \times 132}{6} = 1\,700\,000$ lbs.

From formula (24), $T_s = 3\,630\,000$ lbs.

Live Load, Max. + Mom. at Crown:

$$T_c = \frac{59.5 + 31.5 \times 0.121 + 5 \times 0.121}{1000 \times 0.121} \times 669\,000$$

$$= 0.524 \times 669\,000 = 351\,000 \text{ lbs.}$$

$$M_c = \left[\frac{+67.5 + 80 \times 0.121 + 40 \times 0.121^2 - (20 + 13 \times 0.121)2.25}{10\,000}\right.$$

$$\left. + \frac{3 \times 2.25^2}{10\,000}\right] \times 88\,340\,000$$

$$= +393\,000 \text{ ft. lbs.}$$

Live Load, Max.—Mom. at Crown:

$$T_c = 0.545 \times 669\,000 = 365\,000 \text{ lbs.}$$

$$M_c = -0.00391 \times 88\,340\,000 = -345\,000 \text{ ft. lbs.}$$

Live Load, Max. + Mom. at Springing:

$$T_s = \frac{93.3 - 42.5 \times 0.121 + 155 \times 0.121^2}{121} \times 669\,000$$

$$= 499\,000 \text{ lbs.}$$

$$T_c = \left(\frac{0.545}{2} + 0.524 - \frac{0.0063}{2.25 \times 0.121}\right) \times 669\,000$$

$$= 518\,000 \text{ lbs.}$$

$$M_s = \left[\frac{+322 + 27 \times 0.121 - (18.1 + 13 \times 0.121)(3.79 - 0.073 - 2.25)^2}{10\,000}\right]$$

$$\times 88\,340\,000 = +2\,490\,000 \text{ ft. lbs.}$$

Live Load, Max.—Mom. at Springing:

$$T_s = 0.431 \times 669\,000 = 288\,000 \text{ lbs.}$$

$$T_c = 0.295 \times 669\,000 = 197\,000 \text{ lbs.}$$

$$M_s = -0.024 \times 88\,340\,000 = -2\,120\,000 \text{ ft. lbs.}$$

The arch is reinforced with 24 lines of 1-1/4 in. square bars at top and bottom. The centers of the bars are 3 in. from the faces of the arch, or 1 ft. from the axis at the crown. Hence the moment of inertia

$$I_o = \frac{24 \times 2.5^3}{12} + \frac{24 \times 2 \times 1.56 \times (1)^2 \times 15}{144} = 39.05$$

The equivalent area A_o at the crown =

$$2.5 + \left(\frac{2 \times 1.56 \times 15}{144}\right) \times 24$$

or $A_o = 67.8$ sq. ft.

Fall in Temperature of 40°:

$$\omega t E = 0.000\,0055 \times 40 \times 288\,000\,000$$

$$= 63\,400 \text{ lbs. per sq. ft.}$$

$$\therefore T_c = -\left[18.4 \times 2.25 - 7.5 - (20.5 \times 2.25 - 15)0.121 - (10 \times 2.25 - 2) \times 0.121^2\right] \times \frac{63400 \times 39.05}{16 \times 16} = -289\,000 \text{ lbs.}$$

$$M_c = 20.1 \times \frac{289000 \times 16}{100} = +929\,000 \text{ ft. lbs.}$$

$$T_s - (1.09 - 1.75 \times 0.121)\,289000 = -254\,000 \text{ lbs.}$$

$$M_s = +929\,000 - 16 \times 289\,000 = -3\,695\,000 \text{ ft. lbs.}$$

Average Stresses:

For dead load,

$$f_a = \frac{3\,210\,000}{67.8} \times 0.88 = 41\,700$$

For L.L. producing max. + moment at crown,

$$f_a = \frac{351\,000}{67.8} \times 0.87 = 4500$$

For L.L. producing max.—moment at crown,

$$f_a = \frac{365\,000}{67.8} \times 0.90 = 4800$$

For L.L. producing max. + moment at springing,

$$f_a = \frac{518\,000}{67.8} \times 0.87 = 6700$$

For L.L. producing max.—moment at springing,

$$f_a = \frac{197\,000}{67.8} \times 0.89 = 2600$$

For temperature drop of 40°,

$$f_a = -\frac{289\,000}{67.8} \times 0.83 = -3500$$

For each combination of loading, the arch-shortening thrusts and moments bear the same ratio to the trusts and moments due to a fall of 40° in temperature, as does the total average stress to the stress ωtE (= 63 400 lbs.).

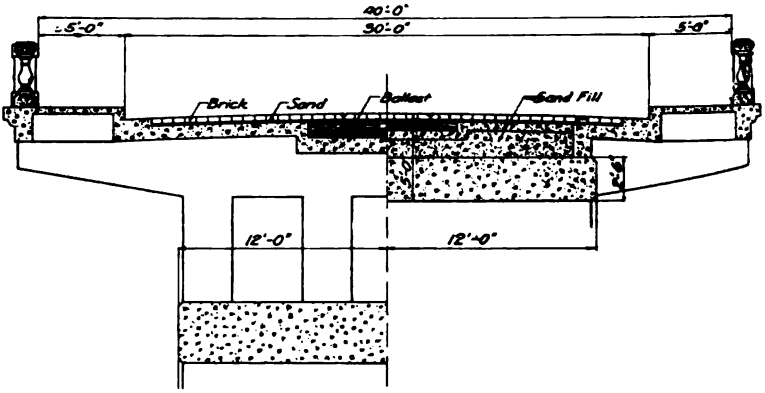


Fig. 21. Sections of 132 Ft. Arch, Kaw River Bridge at Lawrence, Kansas.

The thrusts and moments figured above will now be tabulated, and the thrusts and moments figured by the exact method will also be given for the sake of comparison.

I. SUMMARY FOR MAXIMUM + MOMENT AT CROWN.

(a) D.L., L.L., and Arch Shortening.

Conditions of Calculation		Thrust	Moment	Average Stress
As computed above	D.L.	+3 210 000	....	+41 700
	L.L.	+ 351 000	+393 000	+ 4 500
	Arch S.	— 200 000	+642 000	— 2 400
	Total..	+3 361 000	+1 035 000	+43 800
As computed by exact method.	D.L.....	+3 153 000	+149 000	+40 110
	L.L.....	+ 549 000	+362 000	+ 6 930
	Arch S..	— 203 000	+660 000	— 2 420
	Total....	+3 499 000	+1 171 000	+44 620

(b) D.L., L.L., Temperature Variation, and Arch Shortening.

Conditions of Calculation.		Thrust	Moment	Average Stress
As computed above	D.L. & L.L.	+3 561 000	+393 000	+46 200
	Temperature	— 289 000	+929 000	— 3 500
	Arch S.	— 185 000	+593 000	— 2 200
	Total..........	+3 087 000	+1 915 000	+40 500
As computed by exact method	D.L. & L.L.	+3 702 000	+511 000	+47 040
	Temperature	— 288 000	+940 000	— 3 440
	Arch S.	— 188 000	+613 000	— 2 240
	Total.........	+3 226 000	+2 064 000	+41 360

II. SUMMARY FOR MAXIMUM—MOMENT AT CROWN.

(a) D.L., L.L., and Arch Shortening.

Conditions of Calculation.		Thrust	Moment	Average Stress.
As computed above	D.L.	+3 210 000	....	+41 700
	L.L.	+ 365 000	—345 000	+ 4 800
	Arch S.	— 201 000	+646 000	— 2 400
	Total.........	+3 374 000	+301 000	+44 100

Conditions of Calculation.		Thrust	Moment	Average Stress
As computed by exact method	D.L.	+3 153 000	+149 000	+40 110
	L.L.	+ 278 000	—280 000	+ 3 570
	Arch S.	— 188 000	+615 000	— 2 250
	Total.........	+3 243 000	+484 000	+41 430

It appears from the above that there is no negative moment at the crown.

III. SUMMARY FOR MAXIMUM + MOMENT AT SPRINGING.

(a) D.L., L.L., and Arch Shortening.

Conditions of Calculation		Thrust	Moment	Average Stress
As computed above	D.L.	+3 630 000	....	+41 700
	L.L.	+ 499 000	+2 490 000	+ 6 700
	Arch S.	— 184 000	—2 675 000	— 2 500
	Total.........	+3 945 000	— 185 000	+45 900
As computed by exact method	D.L.	+3 527 000	— 618 000	+40 110
	L.L.	+ 544 000	+2 095 000	+ 6 920
	Arch S.	— 181 000	—2 580 000	— 2 420
	Total.........	+3 890 000	—1 103 000	+44 610

(b) D.L., L.L., Temp. Var., and Arch Shortening.

Conditions of Calculation.		Thrust	Moment	Average Stress
As computed above	D.L. & L.L.	+4 129 000	+2 490 000	+48 400
	Temperature	+ 254 000	+3 695 000	+ 3 500
	Arch S.	— 197 000	—2 860 000	— 2 700
	Total.........	+4 186 000	+3 325 000	+49 200
As computed by exact method	D.L. & L.L.	+4 071 000	+1 477 000	+47 030
	Temperature	+ 258 000	+3 670 000	+ 3 440
	Arch S.	— 195 000	—2 770 000	— 2 600
	Total.........	+4 134 000	+2 377 000	+47 870

IV. SUMMARY FOR MAXIMUM — MOMENT AT SPRINGING.

(a) D.L., L.L., and Arch Shortening.

Conditions of Calculation.		Thrust	Moment	Average Stress
As computed above	D.L.	+3 630 000	....	+41 700
	L.L.	+ 288 000	—2 120 000	+ 2 600
	Arch S.	— 168 000	—2 450 000	— 2 300
	Total.........	+3 750 000	—4 570 000	+42 000
As computed by exact method	D.L.	+3 527 000	— 618 000	+40 110
	L.L.	+ 357 000	—2 206 000	+ 3 410
	Arch S.	— 168 000	—2 385 000	— 2 240
	Total.........	+3 716 000	—5 209 000	+41 280

(b) D.L., L.L., Temp. Var., and Arch Shortening.

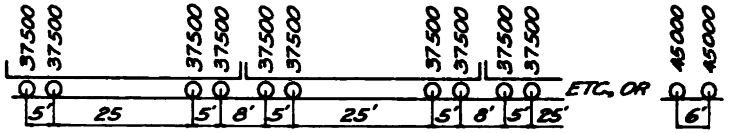
Conditions of Calculation.		Thrust	Moment	Average Stress
As computed above	D.L. & L.L.	+3 918 000	—2 120 000	+44 300
	Temperature	— 254 000	—3 695 000	— 3 500
	Arch S.	— 155 000	—2 257 000	— 2 100
	Total.........	+3 509 000	—8 072 000	+38 700
As computed by exact method	D.L. & L.L.	+3 884 000	—2 824 000	+43 520
	Temperature	— 258 000	—3 670 000	— 3 440
	Arch S.	— 155 000	—2 200 000	— 2 060
	Total.........	+3 471 000	—8 694 000	+38 020

The following table gives the approximate extreme fiber stresses in lbs. per sq. in. computed from the above thrusts and moments on the assumption that the concrete takes no tension:

Method of Calculation.	Case I (a)	Case I (b)	Case IV (a)
By approximate method, using formulas	580	750	420
By exact method.............	620	790	460

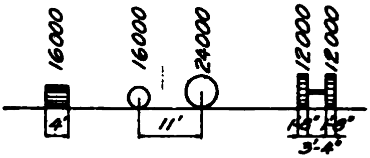
Method of Calculation.	Case IV (b)
By approximate method, using formulas	730
By exact method....................	790

The stresses computed by the approximate method are somewhat less than those figured by the exact method, but if some



A continuous line of 150,000 lb. cars with axle loads as above. *2 axles only.*

Live Load for Electric Ry. Track



20-Ton Road Roller

Fig. 22. Live Load Concentrations, Lawrence Bridge.

arbitrary allowance had been made for the dead load moments the difference would have been less. A good rule for figuring the arbitrary allowance for dead load moments (in case the arch axis is made to fit the dead load equilibrium polygon) is to assume an eccentricity of application of the dead load thrust above or below the axis equal to 1/40 of the depth of the section.

Since this is a rather flat arch, it may be of interest to compare the values of the temperature thrust and moments as figured above with those obtained by the use of the formulas for a parabolic arch, the moment of inertia of which varies as the secant of the angle of inclination of the axis. These formulas are, for a fall in temperature:*

$$H_c = -\frac{45\omega tEI_0}{4h^2}$$

$$M_c = -\frac{H_c h}{3}$$

$$M_s = \frac{2H_c h}{3}$$

From these we get, substituting as above,

$$H_c = -\frac{45 \times 63\,400 \times 39.05}{4 \times 16 \times 16} = -109\,000$$

$$M_c = +581\,000$$

$$M_s = -1\,162\,000$$

Modern Framed Structures, Part II, p. 175.

These values of the horizontal thrust and the moment at the springing are only about one-third of the true values as computed above. It appears from these results that the parabolic arch formulas so frequently given in textbooks are not applicable to concrete arches, except possibly for calculating the live load stresses.

Example 4. The 96 ft. open spandrel arch of the Chauderon-Montbenon bridge at Lausanne, designed by Prof. Melan ("Plain and Reinforced Concrete Arches," by Melan, p. 142).

The axis of this arch lies considerably above the dead load equilibrium polygon, and consequently the dead load moments (neglecting arch shortening) are large. Only the live load and temperature thrusts and moments will be figured. The ordinates of the arch axis are as follows:

x	$c=\frac{x}{l}$	Value of y	
		As given by Prof. Melan	As computed by the formula $y = \frac{8rl}{6+5r}(3c^2+10c^4r)$ $(r=0.177)$
0	0	0	0
6.6	0.0688	0.36 (?)	0.28
13.1	0.1365	1.01	1.11
19.5	0.2030	2.30	2.51
25.8	0.2688	3.94	4.45
31.8	0.3312	6.30	6.92
37.6	0.3915	9.19	9.90
43.2	0.4500	12.70	13.41
48.0	0.5000	16.98	16.98

Since the actual arch axis differs so much from the assumed axis it will be advisable to correct the moments by the approximate method given above. The moments for the assumed axis will first be found and then corrected to give the actual moments. Prof. Melan gives the following data:

Area at crown = A_0 = 8.27 sq. ft.
Moment of inertia at crown = I_0 = 4.64
Live load per lin. ft. of arch = 665 lbs.
∴ wl = 63 800 lbs. and wl^2 = 6 130 000 ft. lbs.
E_c (for temperature effect) = 288 000 000 lbs. per sq. ft.

Coefficient of expansion = $\omega = 0.000\,006\,8$
Variation in temperature = ±40°
Thickness at crown = t_0 = 2.46 ft.
Thickness at springing = t_e = 6.10 ft.
$\therefore u_s = 2.48$

It is to be noted that by Prof. Melan's method of computation the arch-shortening effect is in all cases included in the summations, so in order to compare our results with his we shall have to compute the arch-shortening effect separately for each case.

Fall of 40° in Temperature:

$\omega t E = 0.000\,006\,8 \times 40 \times 288\,000\,000 = 78\,400$
In formula (35), $T_c = -31.1 \times \frac{78400 \times 4.64}{(16.98)^2} = -39\,200$ lbs.
In formula (36), $M_c = 0.193 \times 16.98 \times 39\,200$
$= +128\,000$ ft. lbs.
In formula (37), $T_s = 0.78 \times 39\,200 = 30\,600$ lbs.
In formula (38), $M_s = +128\,000 - 16.98 \times 39\,200$
$= -538\,000$ ft. lbs.

L.L. MAX. + MOM. AT CROWN:

In formula (25), $T_c = 0.369 \times 63\,800 = 23\,500$
In formula (26), $M_c = +0.00461 \times 6\,130\,000 = +28300$
$f_{ac} = 23\,500 \div 8.27 = 2840$
In formula (55), $f_a = 2840 \times 0.86 = 2440$

Hence the correction for $T_c = \frac{2440}{78\,400} \times -39\,200 = -1200$,
and the corrected value of $T_c = 23\,500 - 1200$
$= 22\,300$

The correction for $M_c = \frac{2440}{78\,400} \times 128\,000 = +4000$

L.L., MAX.—MOM. AT CROWN:

In formula (30), $T_c = 0.372 \times 63\,800 = 23\,700$
In formula (31), $M_c = -0.00379 \times 6\,130\,000 = -23\,200$
$f_{ac} = 2870$
In formula (56), $f_a = 2870 \times 0.91 = 2610$
Hence the corrected value of $T_c = 23\,700 - 1300 = 22400$
and the correction for $M_c = +4200$

L.L., MAX. + MOM. AT SPRINGING:

In formula (27), $T_s = 0.512 \times 63800 = 32700$
In formula (28), $T_c = 0.541 \times 63800 = 34500$
In formula (29), $M_s = +0.0297 \times 6130000 = +182\,000$ ft. lbs.
$f_{ac} = 4170$
In formula (57), $f_a = 4170 \times 0.87 = 3630$

Hence corrected value of $T_s = 32700 - \frac{3630}{78\,400} \times 30600$

$= 31300$

The correction for $M_s = \frac{-3630}{78\,400} \times 538\,000 = -24900$

L.L., MAX.—MOMENT AT SPRINGING:

In formula (32), $T_s \;= 0.379 \times 63\,800 = 24\,200$

In formula (33), $T_c \;= 0.200 \times 63\,800 = 12\,800$

In formula (34), $M_s \;= -0.0237 \times 6\,130\,000 = -145\,000$

$f_{sc} = 1550$

In formula (58), $f_s \;= 1550 \times 0.91 = 1410$

Hence corrected value of T_s is

$$T_s = 24\,200 - \frac{1410}{78400} \times 30\,600 = 23\,700$$

The correction for $M_s = -\frac{1410}{78400} \times 538\,000$

$= -9700$

Now to find the corrections on account of the deviation of the actual axis from the assumed, we have the following data:

	At Crown	At Springing
M'_p	$+28300$	$+182000$
M'_n	-23200	-145000
M_1	$+\ 5100$	$+\ 37000$
S_1	51500	327000

We have also

$H_1 = 23500 + 23700 = 47200$

$a_1 = +\frac{5100}{47200} = +0.11$

$b_1 = +\frac{37000}{47200} = +0.78$

$d_1 = 16.98 + 0.11 - 0.78 = 16.31$

Plotting the resistance line for full live load (having the intercepts a_1 and b_1) we get, approximately,

$x_1 = 13, y_1 = 0.99$

$x_2 = 38, y_2 = 9.42$

Then $k = \frac{9.42 - 0.99}{38^2 - 13^2} = 0.00661$

$a = 0.00661 \times 13^2 - 0.99 = 0.13$

$d = \frac{0.00661 \times 96^2}{4} = 15.22$

$b = 16.98 + 0.13 - 15.22 = 1.89$

Hence we have for the crown section,

$$M_p = \frac{47200 \times 0.13 \times \frac{16.31}{15.22} + 51500}{2} = +29000$$

$$M_n = \frac{47200 \times 0.13 \times \frac{16.31}{15.22} - 51500}{2} = -22500$$

and for the springing section,

$$M_p = \frac{47200 \times 1.89 \times \frac{16.31}{15.22} + 327\,000}{2} = +211\,400$$

$$M_n = -115\,700$$

Adding the corrections for arch shortening we get finally:

Max. + moment at crown = +29 000 + 4000 = +33000

Max. — moment at crown = —22 500 + 4200 = —18 300

Max. + moment at springing, = +211 400—24900 = + 186500

Max.—moment at springing, = — 115 700 — 9700
= — 125 400

The table below gives the moments and thrusts as computed above and as given by Prof. Melan:

Loading.	As computed above		As computed by Melan.	
	Thrust	Moment	Thrust	Moment
For max. + mom. at crown..........	22 300	+ 33 000	28 000	+ 34 200
" " — " " "	22 400	— 18 300	18 000	— 18 400
" " + " " springing.......	31 300	+186 500	36 000	+183 400
" " — " " "	23 700	—125 400	22 000	—130 400
For a variation of 40° in temp., crown section........................	±39 200	±128 000	±39 600	±127 800
For a variation of 40° in temp., springing section....................	±30 600	±538 000	±32 000	±544 800

Example 5. The last case chosen will be the large highway arch over the Sitter river near Teufen, Switzerland. This is a very well proportioned arch, designed by Prof. E. Morsch.

The data regarding this arch were taken from *Eng. News*, Vol. 62, p. 133 ff. Since the information given is incomplete, some more or less arbitrary assumptions will be made:

Span of arch axis = 79.64 m. = 261.3 ft.

Rise of arch axis = 25.5 m. = 83.7 ft.

$\therefore\quad r = 0.32$

$t_0 = 3.94$ ft.; $t_e = 6.99$ ft.

Width of rib at crown = 21.3 ft.; width at springing = 24.6 ft.

Since the arch ring is not of uniform width we should find the value of u_s for a rib having a uniform width of 21.3 ft., but having the same moment of inertia as the actual rib at the springing.

Equivalent depth at springing $= 6.99\ \sqrt[3]{\frac{24.6}{21.3}} = 7.33$

$$\therefore\quad u_s = \frac{7.33}{3.94} = 1.86$$

Reinforcement near intrados: Eighteen 1-1/8 in. round bars at crown and ten 1-1/8 in. round bars at springing.

Reinforcement near extrados: Ten 1-1/8 in. round bars at crown and eighteen 1-1/8 in. round bars at springing.

The ratio of moduli of elasticity $\frac{E_s}{E_c}$ will be assumed = 11, as required by the Swiss law.

Take $E_s = 30\,000\,000$ and $E_c = 2\,730\,000$

The coefficient of expansion will be taken = 0.000 006 6

Area of rib at crown:

Concrete, $3.94 \times 21.3 =$ .... 83.9 sq. ft.

Steel, equivalent to $\frac{(10+18)\times 0.99}{144}\times 11 =$

$0.192\times 11 =$ .... 2.1 sq. ft.

Total .... 86.0 sq. ft.

Area of rib at springing:

Concrete, $6.99\times 24.6 =$ .... 171.9 sq. ft.

Steel, equiv. to .... 2.1 sq. ft.

Total .... 174.0 sq. ft.

For the sake of simplicity the moments of inertia will be figured as if the reinforcement were the same at top and bottom, and the center of the steel will be assumed distant three-tenths of a foot from the face of the rib.

Moment of inertia at crown:

Concrete, $\frac{21.3\times \overline{3.94}^{3}}{12} = 109$

Steel, $2.1\times1.67^2 = 6$

Total, 115

Moment of inertia at springing:

Concrete, $\frac{24.6\times\overline{6.99}^3}{12} = 700$

Steel, $2.1\times3.19^2 = 21$

Total, 721

Since no data are given whereby the dead load thrusts may be computed, they will be assumed from the stresses given in Prof. Morsch's table, thus:

$$\text{D. L. thrust at crown} = \frac{250+197}{2}\times86\times144 = 2\,770\,000$$

$$\text{D.L. thrust at springing} = \frac{181+234}{2}\times174\times144 = 5\,200\,000$$

Live load per lin. ft. $= w = 92\times22.6 = 2080$ lbs.

$wl = 2080\times261.3 = 543\,000$ lbs.

$wl^2 = 2080\times261.3^2 = 142\,000\,000$ ft. lbs.

Temperature variation, ± 36 F.

$\therefore\ \omega tE = 0.000\,0066\times36\times2\,730\,000\times144$

$= 93400$

Fall of 36° in Temperature:

$$T_c = -\frac{17.6\times93400\times115}{83.7^2} = -27\,000$$

$$M_c = +\frac{27000\times83.7}{100}\times25.65 = +580\,000$$

$T_s = 0.53\times-27000 = -14300$

$M_s = 580\,000 - 27\,000\times83.7 = -1\,680\,000$

L.L., Max. + Moments:

Crown $T_c = 0.219\,wl = 119\,000$

$M_c = 0.00627\,wl^2 = +891\,000$

Springing $T_s = 0.299\,wl = 162\,000$

$T_c = 0.304\,wl = 165\,000$

$M_s = 0.0263\,wl^2 = +3\,735\,000$

L.L., Max.—Moments:

Crown $T_c = 0.190\,wl = 103\,000$

$M_c = -0.00412\,wl^2 = -585\,000$

Springing T_s $= 0.340\ wl = 185\ 000$
T_c $= 0.105\ wl = 57\ 000$
M_s $= -0.0188\ wl^2 = -2\ 670\ 000$

Average Stresses:
D.L., $f_a = 1.11 \times 32200 = 35700$
L.L. $+M_c$, $f_a = 1.01 \times 1385 = 1400$
" $-M_c$, $f_a = 1.13 \times 1200 = 1400$
" $+M_s$, $f_a = 1.06 \times 1920 = 2000$
" $-M_s$, $f_a = 1.12 \times 660 = 700$
Fall in Temp., $f_a = 0.73 \times -310 = -200$

CROWN:

Max. + Moment:

	Moment.	Thrust	Average Stress
D.L..	. . . . . .	+2770000	+35700
L.L..	+891000	+ 119000	+ 1400
Temp.	+580000	— 27000	— 200
Rib Shortening.	+229000	— 11000	— 80
Total.	+1700000	+2851000	+36820

Direct Stress $= 2\ 851\ 000 \div 86 = +33200$

Bending Stress $= \pm\dfrac{1\ 700\ 000 \times 1.97}{115} = \pm 29100$

Total. . . . . = +62300 or + 4100
or per sq. in. . . . . = + 432 or + 28

Max.—Moment

	Moment.	Thrust	Average Stress
D.L..	. . . . . .	+2770000	+35700
L.L..	—585000	+ 103000	+ 1400
Temp.	—580000	+ 27000	+ 200
Rib Shortening.	+231000	— 11000	— 80
Total.	—934000	+2889000	+37220

Direct Stress = +33600
Bending Stress = ±16000

Total. . . . . = +48600 or + 17600
or per sq. in. = + 338 or + 122

SPRINGING:

Max. + Moment

	Moment.	Thrust	Average Stress
D.L.	......	+5200000	+35700
L.L.	+3735000	+ 162000	+ 2000
Temp.	+1680000	+ 14000	+ 200
Rib Shortening	— 683000	— 6000	— 80
Total	+4732000	+5370000	+37820

Direct Stress = 5370000÷174 = 30900

Bending Stress $= \pm\frac{4732000\times3.5}{721} = \pm23000$

Total. . . . . = +53900 or +7900

or per sq. in. . . . . + 374 or + 55

Max Moment

	Moment.	Thrust	Average Stress
D.L.	....	+5200000	+35700
L.L.	—2670000	+ 185000	+ 700
Temp.	—1680000	— 14000	— 200
Rib Shortening	— 651000	— 5000	— 80
Total	—5001000	+5366000	+36120

Direct Stress. . . . . = +30900

Bending Stress. . . . . = ±24300

Total. . . . . = +55200 or + 6600

or per sq. in. . . . . + 383 or + 46

SUMMARY OF STRESSES.

Location of Stress.	As figured by Prof. Morsch		As figured above.	
	Max.	Min.	Max.	Min.
At crown: top fiber	+444	+117	+432	+122
At crown: bottom fiber	+353	+ 18	+338	+ 28
At springing: top fiber	+409	+ 6	+374	+ 46
At springing: bottom fiber	+421	+ 23	+383	+ 55

The discrepancies are chiefly in the temperature stresses, probably because the haunches are somewhat stiffer than in the case of our assumed typical arch. If the dimensions of the rib in the haunch had been known the temperature thrusts and moments for the assumed arch might have been corrected approximately to suit the actual arch by multiplying them by the ratio of the average moment of inertia of the actual arch to the average moment of inertia of the assumed arch.

PART VIII

USES FOR THE FORMULAS AND DIAGRAMS

It is believed that the diagrams and formulas herewith will be found useful in a variety of cases likely to come up in the bridge engineer's practice. Among the uses for them may be mentioned the following:

1. For determining the form and dimensions of arch rings preliminary to making more exact calculations, thus insuring that but slight changes, if any, will be required as a result of the more precise computations.

2. For final designs in case the conditions correspond closely to those assumed as a basis for the accompanying formulas and diagrams.

3. For determining quickly the effect of unusual concentrated loads, either in the case of a proposed bridge or of an actual bridge.

4. For obtaining the magnitude and direction of the arch thrusts on piers and abutments, thus facilitating substructure design.

5. For making preliminary estimates of cost. The quantities of materials required can be determined with accuracy, thus rendering the cost estimate reliable.

6. For ascertaining quickly and certainly the effect of changes in span length and rise-ratio, so as to determine the most economical layout.

7. For reviewing designs prepared by other engineers.

8. For determining whether a certain existing arch is capable of carrying a given load in safety.

The writer desires to acknowledge the aid of Mr. J. Masuda, who made a considerable portion of the many computations required to develop the diagrams and formulas.

[Discussions of this paper, if received by Dec. 15th, will be published in a later issue of the Proceedings.—Editor.]

NEW METHODS FOR MINING BITUMINOUS COAL AS PRACTICED BY THE H. C. FRICK COKE COMPANY

By PATRICK MULLEN*

This new mining method, as it is practiced by the H. C. Frick Coke Company in the Connellsville region, is the application of shortwall mining machines to the extraction of rib coal.

The two salient factors effecting this result were, first, the effort to reduce accidents; and second, to obtain an increased output of coal per man per day.

It has long been realized that the more intense the supervision of working places and workmen the less liability there was to accident. In order to obtain the desired supervision without making the cost prohibitive, it was seen that the time spent by mine officials in traveling from working place to working place must be reduced to the minimum, and the time actually spent in working places increased to the maximum. To obtain this result the working places were concentrated gradually, and it was soon found that, under the old method of pick mining, a limit was quickly reached; and it was realized that to obtain the desired intensive supervision it was necessary to decrease the number of working places and workmen, which could only be accomplished by an increased production from each miner and a consequent reduction in the number of working places without affecting the total output of the mine. To obtain the increased output per man we turned to machines, but on account of the conditions in the Connellsville region, where it is necessary to drive narrow headings, and narrow rooms with large room centers, it was found that machines in the narrow work would not accomplish the desired result, since the great proportion of coal comes from rib extraction. We knew of no application of machine mining to rib extraction and attacked the problem without any precedent to guide us. In the effort to evolve a method by which mining machines could be applied to the extraction of ribs, the management assigned the writer to this particular work, and his time and efforts were entirely devoted to it.

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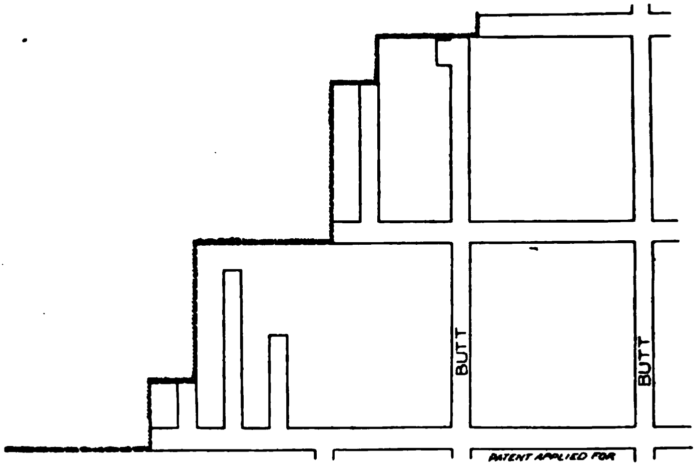
The general shortage of labor which usually exists in this country at times when business is thriving was also an important factor in urging the solution of this problem. The success that has been obtained has resulted as much from the hearty co-operation of every department of the company as from the writer's efforts.

The use of electrically-driven mining machines and the blasting of coal on the very rib line itself requires a system of ventilation that will insure gob gas being found only on the return. Such a system of ventilation necessitates ample, reliable fan equipment, airways of sufficient size and number, a generous provision of upcast openings, wise coursing of the air current and numerous bleeders from every gob into a return airway. It also demands the elimination of danger from dust by keeping it sprinkled and removing it before any dangerous accumulations gather, and in addition demands the use of permissible explosives, and then only in the hands of selected competent shot-firers.

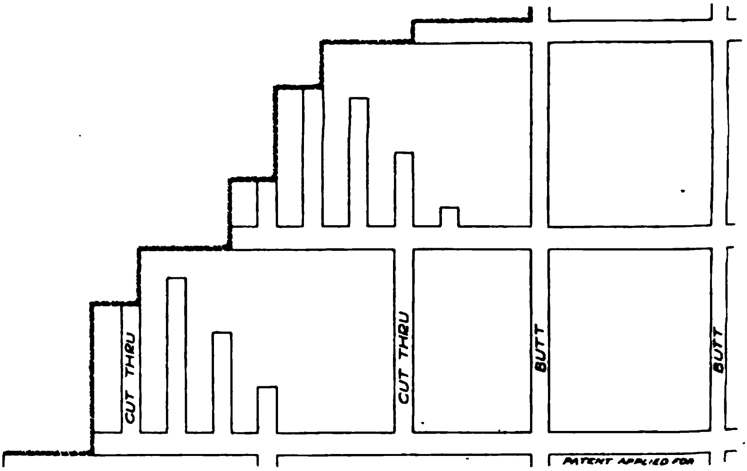
It has been proved that working places cannot be concentrated to as great an extent by any system yet tried in the Connellsville region as by the use of this system of machine mining in rib coal. On account of the intense concentration of working places and the output which is obtained it was necessary that the haulage arrangements and the haulage equipment be perfected beyond anything which had previously been necessary, and the transportation of coal cannot well be handled except by the use of electric gathering locomotives.

The general plan by simple modifications can be made to suit all conditions; depth of cover; presence or absence of drawslate; nature of coal; nature of bottom and roof, and is divided into what we know as *Minimum, Medium* and *Maximum Plans.*

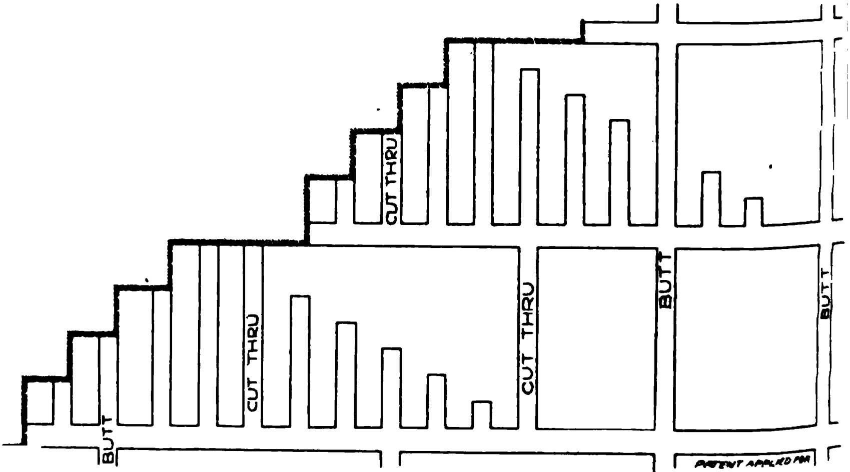
The Minimum Plan may be applied to coal underlying any depth or thickness of cover, whether the coal is hard or soft and the physical condition of roof and bottom good or bad, provided,



MINIMUM PLAN OF CONCENTRATION



MEDIUM PLAN OF CONCENTRATION



MAXIMUM PLAN OF CONCENTRATION

of course, that mining machines in any form can be used.

The Medium Plan is applied where this cover does not exceed 250 ft. with the same physical conditions of coal and bottom and roof as obtains under the Maxium Plan.

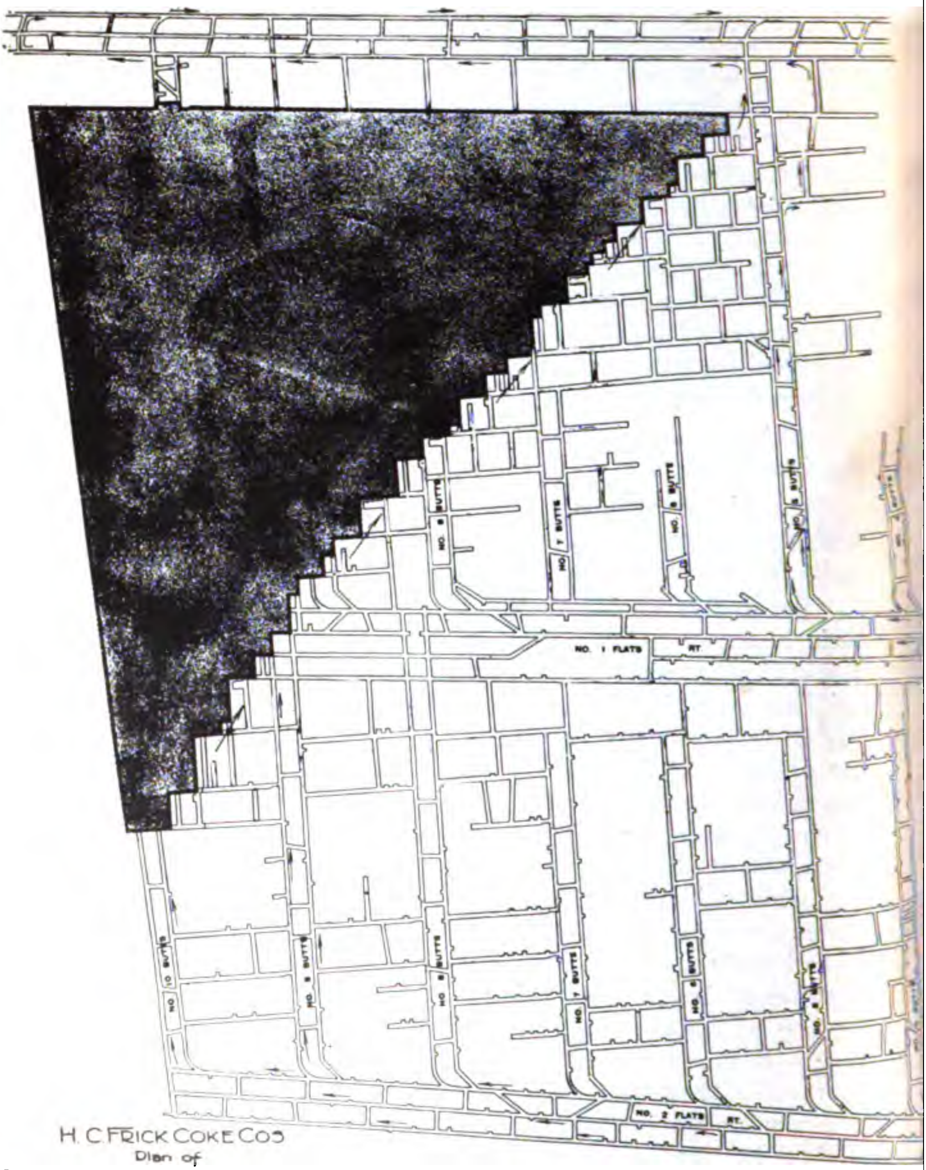
The Maximum Plan is applicable where the overlying cover does not exceed 125 ft. and where the coal is hard and the general physical condition of roof and bottom good.

The H. C. Frick Coke Company has always worked its mines according to a carefully prepared projection of the field of coal to be worked before actual excavations were started. In this plan of concentrated mining it has been found of great advantage to supplement these general projections with a schedule, prepared on a 20 ft. to the inch scale, showing in detail the daily operations.

It should be understood that in the shortwall plan of mining the development is made on the face and butt of the coal.

After it has been determined what plan is to be followed for a given tonnage, the mining section is projected and developed and a fracture line established.

Let us first consider the Minimum Plan of production. The main haulage headings are driven on the face, as are also the return airways, while the producing headings are on the butt, and off these producing headings main face rooms are turned, generally on 112 ft. centers. From these main face rooms, butt rooms are driven on 25 ft. centers. As these main face rooms advance the necks of the butt rooms to be driven are excavated to a depth of three machine cuts. After this main face room has been advanced 50 ft. there are available two places for the machine to cut, which will yield 40 tons, and when it advances to a point where the first cross-cut is turned off there are three places to cut in each main face room, yielding 60 tons. This main room may continue to the end of the section or to the end of the coal field, turning off butts or producing headings at projected distances. The main face rooms, being driven on 112 ft. centers and driven 12 ft. wide, leave a pillar 100 ft. in thickness between these rooms, which pillar we consider ample to support any depth of cover with a floor or bottom under the coal seam of any nature that may be found in the Connellsville region. With this Minimum Plan of production, where main rooms are advanced sufficiently



H. C. FRICK COKE CO'S
Plan of
CONCENTRATED MINE WORKINGS
as used at
CONTINENTAL No.2 MINE
with soft floor

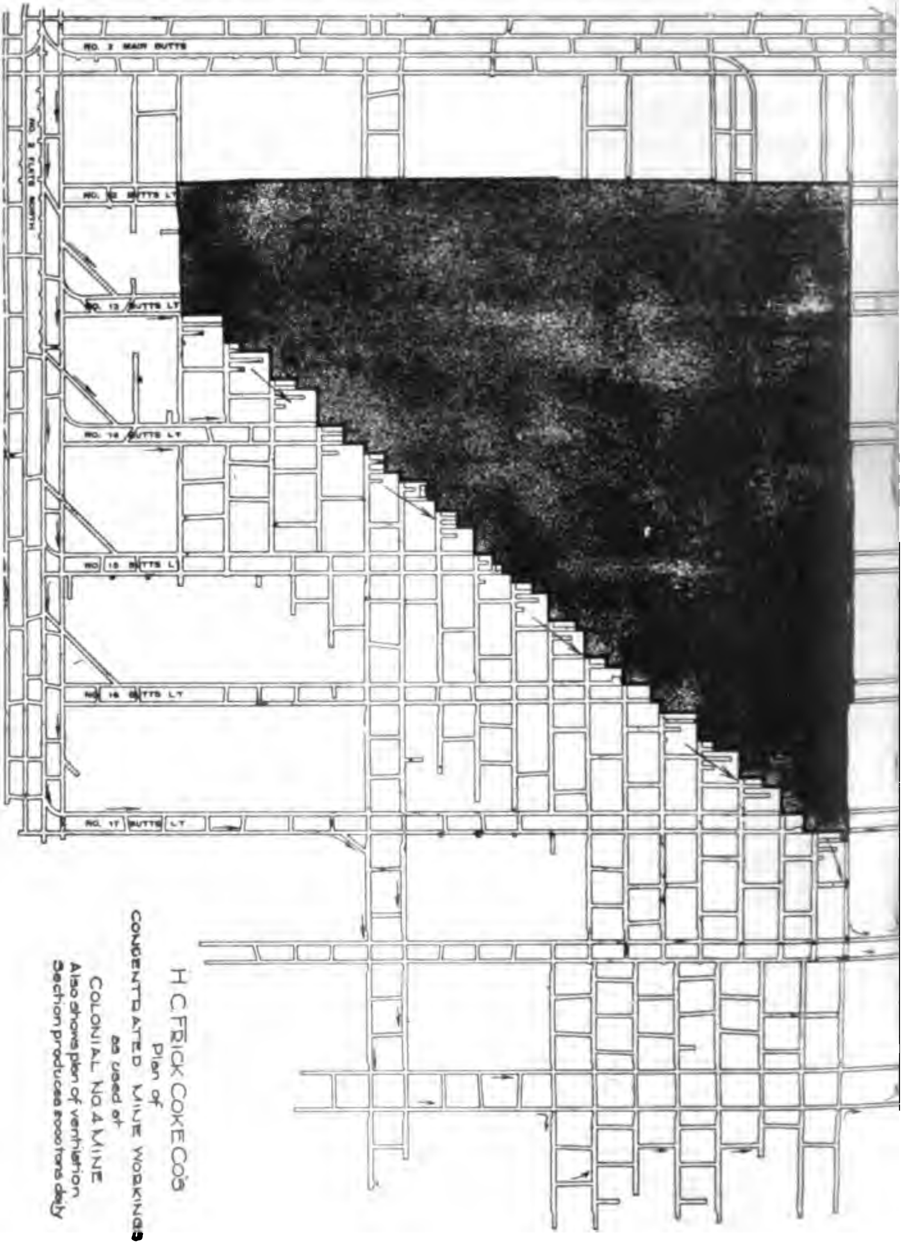
Also shows plan of ventilation
Section produces 1200 tons daily

far to begin the extraction of main face room pillars, the butt rooms are advanced in succession, so that each room is 50 ft. behind the next preceding room. This plan provides for a tonnage output from three working places: Two butt rooms advancing furnish 40 tons and one butt rib retreating provides an additional 40 tons, or a total of 80 tons of coal, while retreating and the main face room advancing is yielding 60 tons, or a total of 140 tons of coal, from one main face room properly prepared and developed on this Minimum Plan of production.

Along the same lines the Medium Plan will not yield any more tonnage from the advancing main rooms, but on the retreat the butt rooms are so driven as to maintain each face 30 ft. behind the face of the preceding room. This allows three butt rooms to advance at a time, which produce 60 tons, and necessitates two butt ribs retreating at the same time, giving a production of 80 tons, or a total from the butt rooms of 140 tons, which with the production of 60 tons from the advancing main room, totals 200 tons for each main room.

In the Maximum Plan the main face rooms advancing produce 60 tons, while the butt rooms are so driven that the face of one is 15 ft. behind the face of the preceding room, thus necessitating four advancing butt rooms and the simultaneous withdrawal of four butt ribs. The four advancing butt rooms will produce 80 tons, while the four retreating butt rooms will produce 160 tons. The sum of these, together with the 60 tons produced by the advancing main room, gives a total tonnage of 300 for each main room.

The work is thoroughly systematized and the routine can be described as follows: After the miner has cleaned up his place and the day's run is completed the machine crew enters and cuts the place to a depth approximating 7 ft. The timbermen follow the machine crew, re-setting any posts which it has been necessary for the machine men to remove, post up any cross bars which have been notched in the coal over the machine cut, and generally put the place in good condition, following out a prescribed system of timbering. The timbermen are followed by the driller, who drills the holes for blasting with an electrically-operated power drill. The driller is followed by the shot firer, who charges the



H C FRICK COKE CO'S
Plan of
CONCENTRATED MINE WORKINGS
as used at
COLONIAL No. 4 MINE
Also shows plan of ventilation
Section produces 2000 tons daily

hole, tamps it and, after his own personal examination of conditions, explodes his charge, blasting down the coal ready for loading. After the coal has been blasted, empty wagons are placed by the gathering locomotives preparatory for the next day's work, so that when the loader arrives at his working place in the morning it is in a safe condition and every facility has been given him to load a maximum tonnage. Especial attention is given through the day so that wagons are changed as soon as loaded, thereby eliminating all unnecessary loss of time and allowing the men to load a maximum tonnage in the minimum time.

Actual results regularly obtained with miners loading under these conditions are 18 to 20 tons per man per shift; the average of all the loaders after shortwall mining machines in all mines of the company for the month of August, 1916, was approximately 19 tons per shift.

The scale of rates for the Connellsville region appertain only to that region and may not be interesting at this time, but all cutting, scraping, loading and drilling are paid for on a piece-work basis; the laying of track, timbering, shooting, hauling and supervision are all on a day-work basis.

At mines where there is a full equipment of mining machines the percentage of machine coal comprises from 80 to 95 percent of the total output.

From the concentration which has been obtained by this method there has resulted a decrease in the cost of transportation, ventilation, track work and drainage, due to the smaller area in active operation; there is also a considerable saving in the amount of money invested in track material and material generally used in the mine.

[The discussion of this paper will appear in the December, 1916, issue of the Proceedings.—EDITOR.]

NEW METHODS FOR MINING BITUMINOUS COAL AS PRACTICED BY THE H. C. FRICK COKE COMPANY

By PATRICK MULLEN

DISCUSSION

MR. A. B. KELLY:* Is it necessary to have laborers do the track work, or do the miners do their own track work?

MR. MULLEN: It is customary for the miner to lay the track in his working place. For motors, or other mechanical haulage, track is laid by laborers. We have very little difficulty in educating our men in this system of mining. We meet with the most opposition from the more experienced men, because these men are fixed in their ways. It is the older and more experienced men and mine foremen or superintendents that balk and who predict failure before they try it.

MR. GEORGE S. BATON:† I noticed on one lantern slide that you had a direct break of perhaps a mile. Do you find any advantages in having the break line so long, and do you run into any troubles on account of the length of the break line?

MR. MULLEN: No, the length of the break line is only made in proportion to the tonnage required. The first slide you saw was in No. 4. It was built for a 2000-ton-per-day output. The last slide was in Continental No. 2 mine, and it was designed for a 1200-ton-per-day output. Both of those were on the minimum plan. In fact, the guarantee that we will have no trouble on account of the room centers being 112 ft. is that each 100 ft. of coal is supported by the extra adjoining 100 ft. of coal, and in the main pillar each man runs his step 12 ft. ahead of the other.

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†Mining Engineer, First National Bank Building, Pittsburgh.

When the coal is extracted the gob falls up against the solid pillar of 100 ft. of coal. We generally found that we could approach a gob that had fallen and it would not be disturbed until after we had the coal extracted. That is the object, supporting those small 25 ft. room centers. The butt room centers are usually 25 ft. apart, and at the other places they are on 30 or 35 ft. centers. That all depends upon the length of the butt room or the tonnage output desired. In the Connellsville region we expect to get 20 tons per working place and we expect to double that in rib work.

MR. W. L. AFFELDER:[‡] You have your butt entries driven in pairs in this mine. In the ideal plan put on the screen first the butt entries were really nothing but straight line break throughs. Which do you consider the better practice, to have butt entries in pairs or chain pillars with continuous break throughs? How does the tendency to squeeze compare in this system with your old room and pillar system?

MR. MULLEN: I believe continuous cut throughs stepped off is the best. As this exists here, driven with rooms advancing, we believe it is a better plan to center from the old pillar, 50 or 60 or 40 percent. We have reached a point where we never hear a squeeze mentioned any more.

MR. GEORGE K. SMITH:[*] Most of us are agreed that the time for improvements in the method of mining bituminous coal has long been due.

As engineers, we have held off too long on the question such as Mr. Mullen has so patiently and thoroughly worked out, and now that we have something different from grandfather's way (due respects to him), let us be ready to apply these newer ideas.

Economy and conservation are prime objects in the bituminous coal-mining business today. These cannot be obtained alone by clever ideas in financing or by half-way attempts at changing from grandfather's methods. From my viewpoint, it would seem that we should go still further than Mr. Mullen has pointed out:

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[*] Engineer, Mechanical Mining Corporation, 1206 Fulton Bldg., Pittsburgh.

i. e., by adopting more complete mechanical means of extracting the coal. This, perhaps, is not quite in line with the subject of the paper, but it bids us pause and think.

Perhaps Mr. Mullen will tell us if undercutting machines are used in the headings and whether the new system has worked successfully where the mine was previously developed along the old method? It would also be interesting to know if falls of the roof are arranged on schedule or allowed to fall of their own accord? If posts are drawn, what, in general, is the size of the roof taken down?

As Mr. Mullen has just stated that they had no squeezes or creeps, may I ask if he considers this due to the fact that the roof is caved in right up to the face of the solid coal, thus relieving the rib of the weight of the overhanging rock?

In view of the concentrated workings, I would ask Mr. Mullen to state whether he considers two assistant mine foremen and four supervisors too many for an output of 2000 tons? Maybe it is not too early to ask also whether the system has made any substantial lowering in the cost of mining, or whether any reduction has been made in the amount of trackage or wire or in general maintenance, and also if the ventilation has been improved and why?

Do I understand that the miners still receive the same rate per car as under the old conditions, or has an adjustment been made?

There is the question of danger from dust settling over such a large gob pile close up to the working face Is it ever sprinkled?

Not all of us appreciate the courage and difficulties encountered by one who attempts to revolutionize the coal industry, such as Mr. Mullen has succeeded in doing. I can well testify to at least one phase of it, having been engaged for several years past in developing machines for loading coal inside the mine. While we are still in the woods, so to speak, the day is not far distant when coal will be mined, not by hard physical labor, but by machines directed by a higher order of intelligence than obtains in the mines today. This progress, or vision if it is such, is very attractive coupled, as it is, to such advanced methods indicated by Mr. Mullen's most excellent and practical paper.

MR. MULLEN: Machines are used and they work successfully, more so when the section has been prepared for them as in the section illustrated. We supervise the roof in making falls. When a fall is ready a man is prepared to make that fall. I will say to you there is not a working place around that mine that is not visited every two hours in the day. Any practical man knows exactly what is taking place and he can anticipate what will be the conditions in two hours, and every fall that is made is made under the supervision of an experienced man. The rooms are on 25 ft. centers, and they usually arrange a fall to be 25 ft. long and 25 ft. deep. As Mr. Smith suggests, the roof is caved up to the face of the coal, thus relieving the weight.

If a trackman or timberman or any other man can do a day's work in one place you get a higher efficiency than if you have a thousand or two thousand tons capacity scattered over three or four sections of a mine. I suppose the increase in efficiency may be 25 percent. To that extent you save on your track, and just in that proportion do you increase his supervision. We effect a saving in wire and trackage, because we can take up and put down more track more quickly.

The gob is sprinkled before it is shot and permissible explosives are used.

MR. W. L. AFFELDER: You also get a far greater efficiency out of your drivers and out of your motormen on account of their being able to gather such a big trip in such a short time and in such a limited space.

MR. MULLEN: Yes, sir. It appeals to me that in concentrated work it gives a higher efficiency per unit. Your trackmen are under your control, your loaders are under your control, your supervisors are under your control, and for all the men you have a higher standard of efficiency. The same is true of ventilation and of track work.

MR. W. L. AFFELDER: I was in a room in one of our mines last week that was just starting this system, and the room had produced 150 tons that day, although rib work was just beginning in that room. It certainly concentrates the work for the driver and for everybody concerned.

Mr. G. K. Smith: How long a working place did you have where you got 150 tons?

Mr. W. L. Affelder: The room was only 140 ft. long. The room was through and some rib work had been started.

Mr. E. J. Taylor:* Under this plan, in order to produce 20 tons per working place, every man is supposed to produce 20 tons, and there is no place for the cripple or the man who is not capable of handling 20 tons. You have got to have men of 20-ton capacity.

Mr. Mullen: There is always a way to figure on an average. We have men that will load 12 or 15 tons, yet there are men who will load 30 tons. That might astonish many men here, but without any special effort, if you will take my word for it, I found a man one day who had loaded 80 tons. I found another man that same day that had loaded 68 tons. There were four cases that were abnormal, without any special effort. Now the loading of the tonnage is not the secret. Neither Mr. Taylor nor myself are as young as we used to be, but there are men as old as he and I that will load 20 tons if it is properly prepared, and they do. It is in the preparation and in presenting to the man the opportunity. If we realize that a man can load 20 tons of coal we must carefully determine what position we are going to put that coal in to give him the opportunity to load it. To tell you my actual experience, I have seen dozens of men by noontime having 20 tons of coal loaded, and not starting to work before 6 A. M.

Mr. E. J. Taylor: Does it require a great amount of care in changing your haulage system to take care of that large amount of coal in such a small area? Your haulage from the faces to the motor road is largely done by mules, I suppose, and where motors are used, do you get them right up to the face of the working?

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*Chief Engineer, Pittsburgh Coal Company, Oliver Bldg., Pittsburgh.

MR. MULLEN: Considerable care is required in changing the haulage system; mules are used in some places, and in others we gather by motors, and where these are used we go up to the face of the working.

MR. W. W. MACFARREN:* I would like to ask first what was the length of time required to develop this system from the time you started at it until it was in successful operation: and second, if there was a cutting and loading machine which was practicable as a commercial proposition to put to work in these places?

MR. MULLEN: Since 1912 we have been conducting a campaign of education among the different mines of the H. C. Frick Coke Company. Today we have at least partially succeeded. The answer to your other question is one of the very vital things. Personally I have never seen a combination machine that was a success. And as far as the loading machine is concerned, its application to the short-wall plan of work, or this plan you see outlined here, and would be of immense benefit to the mining industry.

A MEMBER: You simply have to modify the plan to suit the conditions?

MR. MULLEN: Yes, sir; and that is the reason why we apply the maximum or medium or minimum plan, just to suit the local conditions.

MR. W. L. AFFELDER: In a pitching seam of 3 or 4 or 5 percent, which do you find the better, to work the face rooms right square up the pitch or work your butt rooms up the pitch?

MR. MULLEN: Work the butt rooms up the pitch and the face rooms on the level. That gives you a double opportunity.

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†Mechanical Engineer, 720 Bessemer Bldg., Pittsburgh.

Mr. W. L. Affelder: Do you use this system of working in any of your mines where you are working puncher machines, and does it work equally well with the puncher machines as with the electric, only slower?

Mr. Mullen: I will answer yes to both questions. With practical men time is a factor, and in the extraction of ribs time is very important.

Mr. W. L. Affelder: And that is the reason why you do not have squeezes, because you have limited your time so much?

Mr. Mullen: Yes, sir. It only takes two days to make a fall 25 by 25 ft.

Mr. J. T. Ryan: Will you describe your system of supervision? How many men does each section foreman, for instance, have to look after?

Mr. Mullen: Along a line of that kind (indicating) there will be at least two assistant pit bosses, and they would have under them at least two practical rib bosses.

Mr. G. K. Smith: That means about six supervisors to an output of 2000 tons?

Mr. Mullen: The two rib men are for the purpose of supervising these falls.

Mr. G. K. Smith: That is, two to each system of line pillars?

Mr. Mullen: Yes.

Mr. Robert Linton:* How does the total recovery of coal by this system compare with that under the old room and pillar system?

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*Mining Engineer, 525 Penn Ave., Pittsburgh.

Mr. Mullen: Ninety percent, at least ten to fifteen percent more.

Mr. W. L. Affelder: What about your accidents under this system as compared with accidents in rib drawing in the room and pillar system?

Mr. Mullen: The accidents with short-wall machines, I must say, are very limited. I attribute that more to the faster recovery of the coal and the extraordinary supervision.

Mr. W. W. Macfarren: Could you give us an idea of the expense attached to introducing this system in a mine already developed or well developed?

Mr. W. L. Affelder: We have it in several mines which have been working for years on the old room and pillar system, and we have introduced this system in only portions of the mine in frequent cases, which had not been previously developed. With portions that had been previously developed we modified it to suit that previous development. In other words, we are working this system on 80 ft. centers in some cases, because 80 ft. centers happened to be in existence; and although the system Mr. Mullen has explained is on 110 ft. centers, the 110 ft. centers are not absolutely necessary. The system is sufficiently flexible to suit almost any condition.

Mr. Mullen: The 110 ft. centers are fixed to make rooms of uniform thickness.

Mr. Burns: Does the system work as successfully in these old workings as in new workings?

Mr. Mullen: Yes.

Mr. Burns: I would like to ask about this question of the seam in the system. I cannot see how it would make any difference how heavy the pitch would be. Watching the working place and the falls close behind it, it would not make any difference what pitch it would be, it ought to work just as successfully. If it would work as successfully in old workings it would work as successfully under new development, I would think.

MR. MULLEN: It will work on any pitch that we have found in the Connellsville region or in the Pittsburgh district.

MR. BURNS: Do you think with the pitch in the seam it would push over heavy centers?

MR. W. L. AFFELDER: It is quite likely the system would work on any pitch on which an electric mining machine would work. There is a limit far short of 45 degrees where the electric mining machine will not work.

MR. JOHN SINCOCK:* If by any means you ran into a section of very bad top so it would be impossible to advance that place as fast as the upper and lower ends, how would you maintain your constant output and keep the places in rotation?

MR. MULLEN: If you encountered a very bad top section as you advance, my advice would be that if you knew there was such a bad top that rooms should be driven 12 or 14 ft. wide and then fall it and drive another one parallel with it, leaving a curtain of coal two or three feet deep. Nine times out of ten such conditions will stand.

MR. W. L. AFFELDER: You would compel it to fall and get rid of the weight and then drive another room beside it?

MR. MULLEN: Yes, because you have plenty of coal to drive a room parallel with it.

MR. BURNS: Do you find any difficulty in extracting these stumps with your machine? After break throughs are driven through, in coming back on the return do you have any difficulty in cutting them?

*Asst. Gen. Supt., W. J. Rainey, Uniontown, Pa.

Mr. Mullen: No, there is no difficulty encountered in that. I never encountered any difficulty when they were properly extracted. Many men believe in leaving a stump next the gob big enough, and a good many men do not believe that that should be left next the gob to keep the gob back.

Mr. W. L. Affelder: In drawing your slabs between your butt rooms, do you do your cutting on the gob side of the butt room only, or on both sides?

Mr. Mullen: On the gob side only.

Mr. R. M. Kenney: How many men do you work on the stump?

Mr. Mullen: Usually about two men. It all depends upon conditions. If you get a cut 25 ft. in length and 7 ft. in depth it takes two men to load that.

Mr. R. M. Kenney: Suppose these two men lay off two or three days, does that stop the whole section, or just that place?

Mr. Mullen: Not necessarily. That work is so systematized that if we haven't men we can take the day men.

Mr. R. M. Kenney: Do you have any trouble with draw slate falling and holding up your work in any place any length of time?

Mr. Mullen: We have had trouble with draw slate, and it is common practice between upper cuts to set a post, and after that coal is cut put in another post. In consequence, we have better success in many cases.

Mr. W. L. Affelder: One phase of your question Mr. Mullen did not bring out: The fact that a man in this system does not have an individual place as he does in the Pittsburgh District or in other mining districts. He has an individual place, but there is very little individuality about it, because the cutting is done by a cutter who is paid on a piece-work basis, the shooting is done by a shot-firer with powder furnished by the Company, and all he actually does is to go in and load the coal. If the two men at that place should lay off a couple of days other men could be put in since, as the regular men did not furnish the powder for that shot they do not have any claim to the coal that is there, and anybody could load it.

MR. R. M. KENNEY: At the same time, if you put a man out of the back cut and put him on the stumps, you stop off your front work and you will not come out at the regular time.

MR. MULLEN: It is necessary that the cuts should be taken out every day, and it is the business of the superintendent to see that they are. It only takes eight days to take out those ribs.

MR. WM. ARCHIE WELDIN:* There is one point in Mr. Mullen's paper that I think should be emphasized; that is, the greatly increased supervision compared with ordinary methods and organizations. A few years ago it became my duty to report on the possibility of applying the principles and methods of the Taylor System of Scientific Management to underground operations, and the gains that might be expected from such application.

In every instance of the use of that system I was impressed with the large increase in overhead organization, and I concluded that any application of the newer ideas would require much closer supervision of all labor processes than is cuctomary. I note, therefore, with particular interest this feature of the Frick Company's system and suggest that it would be of value in connection with most mining methods, whether in the coke region, in pitching seams, or under other conditions.

The additional cost of extra supervision should be absorbed in increased efficiency resulting therefrom, and it is of direct value in controlling falls and in promoting safety, discipline, etc.; these gains in addition to those resulting from concentration, as pointed out by Mr. Mullen.

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*Of Blum, Weldin & Co., Consulting Engineers, Pittsburgh.

MR. BURNS: Will this system work successfully with pick rather than machine mining, and is the success not due to the short-wall machines?

MR. MULLEN: Time is a very important factor in the extraction of coal, and if you apply a machine in a 100 ft. room you cut through in 14 days. But let a man hew through with a pick and it might take him 28 days. You can imagine what the condition of that 14 or 15 ft. of rib would be in 28 days. It would be impossible to do that with the slower process and, as pointed out in the paper, you haven't the men.

MR. W. W. MACFARREN: What proportion of the time are these short-wall machines actually cutting coal, and what proportion of the time are they being moved from one working place to another?

MR. MULLEN: I have seen men who could handle a short-wall machine and keep it going all the time. Yet usually it takes a half-hour to load up the machine in one place and move it to another. The actual loading and transportation might take 60 percent of the time and the cutting 40 percent. That is the reason why the application of the short-wall machine made the short-wall plan of mining successful.

MR. W. W. MACFARREN: Your average would, I think, indicate about 40 percent efficiency for the short-wall machine based on the assumption that working all the time would be 100 percent efficient.

MR. W. L. AFFELDER: But with this system that percentage is less than it would be if there were larger moves to make.

MR. W. W. MACFARREN: I understand that, but I am trying to see what the limit is in that direction. There is still some improvement possible, theoretically.

MR. W. L. AFFELDER: It is your later practice to do this cutting at night and the loading in the daytime?

MR. MULLEN: Yes. The paper enumerated the proceedings, cutting, drilling, shooting and placing the wagons in the nighttime.

MR. W. W. MACFARREN: How do you do your drilling?

MR. MULLEN: By machine, most of it with portable electric drills. The portable drill used is simply a modification of a shop drill, a portable electric shop drill in most cases. The coal is comparatively easily drilled. Two men hold the drilling machine with a full-length auger up to the coal and the machine does the rest. No post is used.

MR. GROVE: In driving up this main room do you keep the side rooms straight, and is it not true that this system of mining requires a relatively smaller amount of air to be handled in the plant than in other systems where the working places are more scattered?

MR. MULLEN: Yes, sir; in order to keep a uniform thickness, and it is true that less air is handled.

MR. J. W. CAMPBELL:* From an engineering standpoint this system of mining takes less engineering. We have engineers that will drive 160 points a day, which they cannot do with other systems.

MR. W. L. AFFELDER: You drive all these butt rooms by sights?

MR. J. W. CAMPBELL: Yes, sir; three men can drive 168 points a day.

MR. BURNS: Do the day men do all the posting?

MR. MULLEN: No, the miner does the ordinary timbering.

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*Division Engineer, H. C. Frick Coke Co., Uniontown, Pa.

Mr. Robert Wood, Jr.:† Mr. Mullen mentioned that the company gave free powder. Is this general and does your company furnish free powder, i. e., The Bessemer Coke Company?

Mr. W. L. Affelder: We make our rate of pay take care of that.

Mr. Robert Wood, Jr.: I question the changing of men from one working place to another. Where you have only 50 percent of your men at work, does it make any trouble at all in changing them around?

Mr. W. L. Affelder: Yes, it might, if it was a common practice to do that. In other words, another loader would get the benefit of the powder furnished by the man working the day before. It would affect it to some extent. But as Mr. Mullen brought out, although the ideal way is to keep the system absolutely uniform, it is not absolutely essential. In other words, the system is flexible enough to allow some variation in the speed of work, just the same as the ordinary rib-drawing system is subject to fluctuations due to men laying off. The system would be far more ideal in bad times when men are plentiful than in good times when men are scarce.

Mr. Robert Wood, Jr.: But you see this system at the worst when labor is short?

Mr. W. L. Affelder: Yes, as far as the ideal conditions are concerned, but at its best on account of the immense product from the few men you have.

Mr. W. W. Macfarren: If you were to furnish free powder for the miner under present conditions of scarcity of men and take it off the price of the coal, what would be the result?

Mr. W. L. Affelder: It depends pretty much on how it is handled.

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†Asst. Gen. Supt., W. J. Rainey, Uniontown, Pa.

MR. W. W. MACFARREN: Do you think they would stand the decrease of the rate per wagon if you furnished the powder?

MR. W. L. AFFELDER: I do not see any special reason why they should not. On the other hand, why introduce complications of that kind in times like these? It is not necessary to the system for the company to furnish the powder. In a great many mines owned by companies other than the Frick Company, the men actually do furnish their own powder for exactly this same system.

MR. MULLEN: I would like to make this statement, the record of the average output per day is 19 tons a man. This is not a guess, but is an actual record.

MR. W. L. AFFELDER: I stated before that Mr. Mullen's 19 tons was not an exaggeration, but it is hard for a Pittsburgh District man to realize that we do get such results. We have one plant that is only working to a small extent on the concentrated system and the rest of it is working on development work; yet we count on 17 tons of coal for each loader in that mine every day, and we get it. Some are producing far above 17 tons in the concentrated work, but the average in the entire mine, with at least one-sixth of the coal pick coal, is 17 tons for every loader that goes into the mine in the morning, good, bad and indifferent. The same mine was producing eight tons of coal per man on a pick basis a couple of years ago.

MR. P. S. KING:* From the viewpoint of safety, the system as developed by Mr. Mullen has been an undoubted success. The reduction in the actual number of men engaged in a certain production reduces the total number of hazards by having fewer persons subjected to the risks, without increasing greatly the individual's hazard. This results directly from the increased correlation of the work of production, in which the system excels.

The limiting factor in the system is the proximity to each other at which the efficiency of the men at the working face can be maintained. In decisions as to this, Mr. Mullen is unrivaled, as it requires judgment and ripened experience combined with capacity for detail, of an extraordinary type, to follow it up. It also requires trained supervision of local men, such as the H. C. Frick Coke Co. has been establishing at no small cost, to captain each group of productive places.

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*Inspector, Twenty-ninth Bituminous Inspection District, 612 N. Canal St., Pittsburgh.

From my own observation, what appeared to be the greatest difficulty was the taking out of the last lifts of the pillars, but this is not often a danger with this system, because the movement of the gob-line is rapid and also because the weight of the superincumbent strata has a more solid resistance to abut against, and the zone of subsidence does not encroach upon the coal being worked so far as in the ordinary method, and hence, the coal does not suffer from crush, since the time each pillar is subjected to the weight is comparatively short. The same may be said about the timbering, which usually, although it may become damaged, is not required so long as to lose its initial strength and seldom requires replacement.

The open-mine area is reduced so much that the limiting number of men permitted in a split by law is soon reached. However the facility of ventilating with a large quantity of air is apparent, communication being easy between the places and the length of broken workings to be ventilated short. This applies also to transportation, drainage and supervision.

The certainty of production, with the management of the gob and work presumed by this system is its chief recommendation. This is made possible by the division of labor practised, which is suited to limited time-unit performance, assuring co-operation, the crux of the concentration of work by this method.

The cost varies from 0 to 12 percent below the best of other methods, according to the initiative and the proficiency attained in the application of the system.

FACTORS AFFECTING COSTS OF STRUCTURAL STEEL SHOP WORK

By E. W. PITTMAN*

The Executive Committee of the Structural Section suggested a discussion of this subject by several men with shop experience and a knowledge of shop costs. The purpose of the two papers to be read this evening and the discussion which is expected to follow is to afford to engineers and architects called upon to design steel structures some general data as to costs.

Many of the factors affecting costs are under the direct control of the designer, and a knowledge of these factors and of relative costs should enable him to take advantage of economies that would not otherwise be apparent.

Before entering into a discussion of the factors that effect the cost of structural steel shop work, a brief description of the methods and routine that prevail in modern shops will not be out of place.

The first and most important step, following the original conception of a steel structure, is the general design. The engineer endeavors to incorporate in the design drawings all information and data necessary for making the shop detail drawings. When the design drawings are complete and comprehensive much time and misdirected effort is saved in the drawing room. When time permits, it is customary to make the shop drawings and check them before compiling a list of the steel required. Generally, however, time does not permit of this procedure, and it is necessary to order the steel from the rolling mills promptly. In this case a few preliminary sketches and layouts are made in the drawing room to determine the sizes and lengths of pieces. Using such sketches and layouts in conjunction with the design drawings, a list of pieces is written for each member in the structure. From this list the mill order for the steel is compiled by segregating the various sections and multiplying the short pieces into longer lengths. Each item on the mill order of one or more pieces of a given size and length is assigned an item number and this item number serves to identify the piece after it leaves the mill. It is desirable to reduce to a minimum the number of item numbers used, but at the same time the waste in multiplying should not be excessive. It is the practice in some shops to order all detail material in 30 ft. or 40 ft. lengths without reference to whether or not these lengths are an exact multiple of the short lengths into which the pieces are to be sheared. This is convenient for the shops, but it involves considerable loss in cutting, and is not economical, unless good use can be made of the excess material.

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During the interval between the ordering of the steel from the mill and its delivery, the shop drawings are completed and checked and the finished list of material for each member is written. Frequently also the wood and cardboard templets and wood poles for spacing punches are made and checked before the steel is delivered from the mill. If the mill order involves a great variety of shapes, a considerable period sometimes elapses between the beginning and completion of deliveries from the mill. This, of course, enhances the difficulty of storing the steel and having it accessible for use in the shop at the time when final delivery is accomplished. It is not economical, as a rule, to start the fabrication of a structure until all the steel is delivered.

The steel is moved from the storage yard to the punching shop on requisitions issued by the punching shop. These requisitions are written from the finished lists of material that are made in the drawing room. In order to utilize the economies that result from duplicate spacing, it is customary to punch at one time all pieces that may be laid off from one templet or that may be passed through the spacing punches with one set-up of the die and punch holders and stops. It frequently happens, therefore, that the fitting and riveting cannot be started advantageously, especially on small jobs, until the punching is completed or well advanced. Any delay to the fitting and riveting department on account of not having punched material when needed is a dead loss. After the members are fitted and bolted up they are reamed and riveted. Subsequent operations comprise planing, chipping, boring, weighing, inspecting, painting and loading.

We will return now to a consideration of some of the factors that affect the costs of the foregoing operations. The engineer in making the design and writing the specifications for material and workmanship has many alternatives to consider. He has a creditable ambition to produce something original and to specify the best of materials and workmanship, and at the same time he is conscious of an obligation to his client to keep the cost of the structure within reasonable limits. The largest single factor in determining the cost per pound of steel in a structure is the design rather than any special or unusual requirements as to workmanship. If utility and economy are the governing considerations, the design should be as simple as possible. The number of members and the number of pieces in each member should be reduced to a minimum. Complicated connections and splices and bent work should be avoided as far as practicable. The use of a great variety of sections and of sections not often rolled should also be avoided. This is especially important if quick delivery is a consideration, as it is easier to procure mill rollings of a few standard sections than of a great many including some unusual ones such as *T's*, *Z's* and deck beams. It is always well to go over a design after it is finished and make a list of the different kinds of sections shown. Generally it will be found possible to greatly reduce the number without materially increasing the weight. In ordinary structures such as small bridges, viaducts and buildings, it is well to make liberal use of beams, channels and *H* columns in place of short lattice struts and trusses and small built up columns. It is interesting sometimes to observe the transformation in a mill building design at the hands of a bridge company with a financial stake in simplifying the work. I have seen designs made up of a fretwork of lattice members, short trusses, riveted columns and plate girder crane runways redesigned in the interest of economy with *H* columns in place of built up columns, beams in place of roof trusses and lattice struts and girder beams in place of plate girders. The cost per ton to the purchaser for the manufacture of the original design, exclusive of the cost of steel, might be about $15 to $18 a ton, while the cost for the revised design should be about half this amount. Of course, the substitution of rolled sections for built up sections sometimes increases the weight slightly. Using these figures as a basis of calculation, however, and knowing the base price of steel at any time, it is an easy matter to determine just what increase in weight would be compensated by the decrease in cost of fabrication.

In the design of shallow plate girders it is sometimes economical to increase the thickness of the web plate 1/16 in. beyond the thickness required to resist the shearing stress when such increase renders it possible to dispense with stiffener angles and fillers that would otherwise be necessary. Likewise it is often economical to distribute a column load over a masonry footing by means of a thick slab rather than by means of a number of stiffener angles, wing plates and diaphragms at the base of the column. Stiffeners at the bottom of a column require careful planing and fitting to be effective, and frequently also they involve many hand rivets.

It is often necessary to use two or more different size rivets in a structure. But when this is necessary an effort should be made to avoid as far as possible the use of two or more different size holes in the same piece, as this involves the transferring of the piece to another punch, or else the changing of punches and dies in the machine. This almost doubles the cost of the punching on the piece.

Some of the rolling mills used to issue a card giving fabricating extras on beam work. The extra listed on these cards for two or more sized holes in a beam was a considerable item.

Entering or pocketed connections and over-lapping splices, both in the shop and field, should be avoided as far as practicable.

In writing the specifications for workmanship the engineer must consider and determine the requirements for sub-punching and reaming, drilling, planing and templet reaming. The practice of sub-punching, that is, punching holes 1/8 in. or 1/4 in. small and reaming to the finished size, after the work is fitted is more common now than it was a few years ago. It insures good matching of holes and good rivets, and is, no doubt, a wise requirement in the case of railroad bridges. But when the requirement is extended to buildings and light bridges and viaducts it probably costs the purchaser more than it is really worth to him. The facilities in modern shops make it possible to punch holes full size and obtain fair matching without any reaming at all. Generally a hot rivet may be easily entered in three-fourths of the holes, but all holes are cleaned out with a five flute tapered reamer in a portable hand machine. This has the effect of dividing any error in the matching of holes by slightly elongating the mismatching holes, and it is an insurance against any delay in sticking in the rivets. This hand reaming is done on the skids where the work is fitted up and bolted. But if the work has been sub-punched and must be reamed out 1/8 in. or 1/4 in. larger, it is cheaper to remove the pieces to the reaming machines and do the work with a three flute straight reamer made of high speed steel. This generally involves a great deal of crane service and trucking in addition to the increased reaming cost. The increased cost to a purchaser for sub-punching and reaming probably varies from 60 cents to $1.00 a ton. A requirement often seen in specifications is that material over a certain thickness must be drilled from the solid. This is a matter that should be left somewhat to the judgment of the shop, or to the purchaser's inspector, especially if the punched hole is to be subsequently enlarged by reaming. In average bridge steel it is easily possible to punch 11/16 in. holes in 7/8 in. metal, or 13/16 in. holes in 1⅛ in. metal with good results, using a die about 1/16 in. larger than the punch. If the steel is hard, however, this is not feasible. If the steel is very hard and 11/16 in. holes are required, it is often preferable to drill even 11/16 in. metal because of the loss and also the danger from breaking punches. The labor cost of drilling in a well equipped shop is about five or six times that of punching.

In bridge work it has become quite common of recent years to require the assembling and reaming at the shop of important field connections, or else the reaming of such connections through a steel templet. This adds considerably to the cost of fabrication, but it generally saves more in the field than it costs in the shop. This requirement should not be made, however, without a careful study to determine its economy. Sometimes a connection may be reamed cheaper in the field if it is easily accessible without scaffolding.

SOME ITEMS AFFECTING COST OF STRUCTURAL STEEL WORK

By George H. Danforth*

This subject is not new: It is really old. In fact as old as the fabricating business itself, and there is hardly a situation which arises in the structural steel business today that affects costs, that does not have a corresponding item back in the days when our predecessors were endeavoring with the much more limited sizes of material and very much more limited equipment, to wrestle with the problems of their day.

Probably the first point that should be considered in looking out for the reasons of high costs is the matter of fitness of design, as it is an unfortunate fact that some designers seem to think more of building a monument, or of establishing a reputation for a wonderful design, than they do of making a simple piece of work that can be readily built of easily available material.

As an illustration of this point of view, a friend of the writer had occasion to put up a tank to hold some twenty or thirty thousand gallons of water. As he wanted to be sure of his ground he sent out inquiries to people who built tanks, and at the same time wrote his consulting engineer to make a design of a suitable tank. The consulting engineer in the case evidently saw an opportunity to build a monument, with the result that he forwarded to his client a design that involved a hemispherical bottom, steel legs with the usual bracing, and some circular girders to reinforce the tank at the points where the legs would connect to it, together with a nice fancy, and incidentally expensive, roof over the tank. The cost of all this was fully three times what a plain circular tank with a flat bottom would cost, and the extra expense would be simply money thrown away.

Another illustration of the same point of view also hinges on a tank. In this case the tank was to be placed at an elevation of about 20 ft. above the ground, at a stone quarry, and the owner desired a concrete support. This problem placed in the hands of an engineer resulted in a design of a series of reinforced concrete columns, girders and slabs on which the form work would be very high, as there was no chance of using the forms more than once. It was, however, reasonably economical both in reinforcement and in concrete, but considering the fact that the owner considered the stone as costing him nothing, the cement very little and the reinforcement a serious item, it did not take any argument to convince him that a plain rectangular box, on which forms could be used over and over again, with a flat slab on top to receive the tank, was by far the most economical.

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Another item of design in which a high cost is frequently incurred to save a small amount of material is in the use of riveted trusses for roofs and similar places, when a simple beam will answer all purposes, and there are a great many cases where roof trusses are used on spans of thirty to forty, or even forty-five feet, where a simple beam would answer all the purposes, weigh possibly a trifle more, but cost in dollars and cents considerably less. This feature is, of course, subject to modifications, due to the variation in the price of material and the price of labor. At the present time it would probably be economical to spend a little more in labor to save something in material, but even at the present time the saving, under these conditions, would not be as great as might be imagined, and the greater stability and ease of cleaning and painting that attaches to the use of a simple beam over that of a roof truss, which has a considerable proportion of its surface inaccessible, is plainly evident.

This idea of getting economy by the use of simple sections in place of complex riveted sections is nothing new. In the days when channels were held at prices of three cents and over, with angles and plates about half this price, it was a common practice to make bridge chords, even of small highway bridges, of four angles, two web plates and a cover plate, in place of two channels and a cover plate, the conditions in the prevailing prices for material more than offsetting the additional shop work of using the plate and angle section.

Another item that will occasionally affect costs and also affect delivery is the number of sizes that a designer will put into a structure. For instance, there is not sufficient difference between the dimensions of a 6 x 4 in. and a 6 x 3½ in. angle to prevent the use of either size throughout a job, rather than use both sizes. This is also true of 5 x 3½ in. and 5 x 3 in. angles, 3½ x 2½ in. and 3 x 3 in. angles; also 2½ x 2½ in. and 2 x 2½ in. angles. Each size that can be thus eliminated from a job means one less size to be realized before the fabrication of the job can be taken up, and so expedites delivery and reduces the work and troubles in putting through a piece of work.

In this connection it might be well to mention that even nowadays we occasionally run across work wherein tees have been specified by the designer, in happy ignorance of the fact that there is probably not a more difficult section to get, even under normal mill conditions, than such tees.

The same is similarly true, although in a lesser degree, of small beams and channels. Many designers use these sections for lintels, when two or three angles could just as well be used, and which would eliminate any necessity for punching or for separators or separator bolts, and with no appreciable increase in weight.

Going further into detail you will find the matter of detail design, which of course involves the question of shop drawings. It seems impossible to some people to make details without getting rivets into pockets, where they are very difficult, if not impossible, to drive; or of building up a section which has to be partially assembled and partially riveted before the balance of the sections can be put together and the piece finished. There is also a tendency to use an excessive number of rivets. A few excess shop rivets are not serious and do not appreciably increase costs unless the excess is great.

The contrary, however, is true in regard to field rivets, as we frequently find field rivets put in with a free hand, utterly regardless of what it will cost the erector to drive them. In one instance which occurs to me the designer insisted upon using 24 rivets to hold up one end of a 24 in. beam, which was not subject to any excessive load, and very carefully arranged the details so that 18 of these 24 rivets would be down in a pocket where it was impossible to properly back-up the rivet in driving.

Another case was the extension to a smokestack, where the new and the old stacks were to be connected together by means of two angle rings. In arranging for this splice the new ring on the bottom of the new stack was carefully punched with holes every 6 in., evidently forgetful of the fact that the ring on the top of the old stack would have to be drilled by hand from a swinging boatswain's chair, and that every hole would probably cost at least one dollar. Holes spaced two or three feet apart in that particular case would have been ample to have kept the two pieces of stack in line.

Another detail item that seems to receive little attention, outside of drawing rooms that are directly in charge of a shop superintendent, are changes in sizes of holes and in sizes of rivets. This is a frequent item of expense and a constant source of trouble, as unless everyone connected with a job is constantly on guard the condition will arise where a member that has been built using ¾ in. rivets will connect into a member that has been built using ⅞ in. rivets, and the holes for the field connections, instead of being the same size, will be of different sizes. In other words, of sizes suitable for the size of rivets used in the individual member.

It also pays well in arranging pitch lines and in spacing of rivets and of open holes to so arrange this spacing as to permit of the use of a rack punch or spacing table. For this purpose fine divisions in spacing should not be tolerated, and holes should be in line longitudinally, and the use of such a thing as an offset gauge absolutely prohibited. Simplicity of detail will always tend toward low costs. In connecting beams to girders or to columns it is always advisable to connect them either by the flanges or by the webs, whichever seems preferable, but it is never well to connect a beam by both flange and web, as bad holes are almost always the inevitable result, owing to the methods necessarily pursued in laying out the material.

Another item of similar character is the matter of gussets. Occasionally we see cases wherein the designer, in an effort to keep down his weights, has used a gusset so thin that he is afraid it is lacking in stability, and therefore reinforces the gusset by tacking on flats or angles to the edge, as stiffeners. This adds very materially to the costs, and could readily be avoided by making the gusset a trifle thicker. In many cases an increase in the thickness of a gusset of 1/16 in. would remove any reasonable doubt of its stability and would eliminate any supposed necessity for stiffening its edges.

Column splices constitute another item wherein much money is often uselessly spent. With the ordinary plate and angle columns there is not much need of any splices other than plates on the flanges. An attempt to splice the web also frequently results in bad holes and other difficulties, while a web splice arranged with angles generally serves no useful purpose other than covering up, possibly, a case of a poorly milled end.

Stiffeners on plate girders are often called for as being fitted at both ends. What useful purpose is accomplished by this fitting it is hard to see. For end bearings and intermediate concentrated loads it is of course necessary to have the end of the stiffener that receives the load properly fitted to the flanges, but aside from this there is little use in spending time and money in making a snug fit between the ends of stiffener angles and the flange angles.

In closing this little essay it might be well to mention the fact that due attention is rarely given to the economies of duplication. To build one truss is expensive, but to build a large number of duplicate trusses is a relatively cheap operation, and it would frequently be economical to make a large number of parts of a structure exact duplicates, even though it involved more material than it would to make each separate and individual truss or part specifically designed for its work.

DISCUSSION

MR. SAMUEL E. DUFF:* In discussing this subject, I think it well to point out at the beginning that there are two points of view, perhaps not greatly divergent, but in many respects entirely different. The authors of the paper tonight have made no distinction between these two points of view, and I fear improper conclusions may be drawn from some of their statements on that account.

The title of the paper comprehends both points of view. To cover the matter properly there should be two titles,—one, "Factors Affecting the Costs of Purchasing Structural Steelwork," and the other, "Factors Affecting the Cost of Producing Structural Steelwork."

It may appear at first that these things are identical, but such is not the case; and as I presume this paper is intended primarily for the instruction of engineers who have not served their time in the structural steel business and for the education of the younger engineers, I think it proper to call attention to the two principal phases in which the cost of structural steelwork must be considered.

The engineer in private practice, or the architect whose duty it is to design a structure composed largely of structural steelwork, is first concerned with the question of making his structure adequate in strength. His obligation to his client requires him to make a design which will enable the structural steelwork to be purchased for the least sum of money—the adequacy of the construction being assumed.

No engineer or architect should attempt to design structural steelwork unless he is thoroughly familiar with the technical knowledge required to determine the adequacy of the design for the loads it is to carry. In order to obtain the second condition—least cost to the owner—the average engineer or architect of experience will endeavor to so design the work that it will have the least possible weight in it. There is usually so much competition in this business that low bids can be obtained by seeking many bidders, and the bids are really based on the weight of the steel to be furnished.

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With this only in view he is liable to put a great many things into his design which will cause wailing and gnashing of teeth among the draftsmen and workmen engaged on fabrication and erection; but, on the other hand, he may get what he is after—low cost to the owner.

Now the point I want to emphasize is that had the designing engineer or architect given the greatest possible attention to producing a design of great *uniformity* throughout, as well as one requiring the least possible weight, he would have obtained lower cost for his owner and produced a more friendly feeling on the part of the contractor and his assistants. The proper point of view, therefore, for the independent engineer or architect is to produce designs as light as they want them, but with every possible condition which permits exact duplication of parts.

I wish to emphasize as strongly as possible, therefore, that the buyer of structural steelwork should obtain a design containing the greatest possible number of units which are exact duplicates, made of material and produced by methods in which there is great competition. At this point I wish to call your attention to the fact that a large proportion of the engineers or architects who are making designs for steelwork are not able to determine when units are exact duplicates in the same sense in which this statement is understood by the engineers and designers of the fabricating contractor.

The best way to learn what is required is to compare the original design of the independent engineer or architect with the shop detail drawings made at the fabricating plant. If the number of detail drawings required is large, it usually indicates that the original design has contained a number of differences in units which seemed trivial to the original designer, but which required the fabricating contractor to make separate sketches and drawings for numerous pieces which the designer considered identical. A comparative study of general design drawings and detail drawings will throw a great flood of light on the subject to the average engineer and architect.

Many engineers and architects believe that any changes in general drawings after the contract has been made are bound to be in favor of the contractor, and they, therefore, generally refuse to permit the fabricating contractor to make any changes when he is getting out his detail drawings. In fact, the general rule is for the engineer and architect to say "no" before they have taken the time to examine what is proposed. A much wiser course is to encourage suggestions from the engineers of the fabricating company, and examine them carefully before rendering a decision.

In many cases doubtless the owner might obtain no advantage by adopting the suggestions of the contractor, for a contractor is in business to make money, and few of them are so foolish as to make suggestions which will cost them anything. The great value of the architect and engineer will be the education as to what things the contractor considers favorable to himself, so that in future designs the architect and engineer can approximate more closely the most efficient practical design.

In other words, it is the business of the independent engineer and architect to use every means to find out how the owner—his client—can procure the results required for the least money, and in the case of fabricated steel, no one can tell him so much about this subject as the engineer for the fabricator, but the architect should remember that this engineer is not likely to give him the benefit of his knowledge unless the application of it is of benefit to his employer—the fabricating contractor.

A buyer should keep always in mind that those things are most easily and cheaply obtained which are produced in greatest quantity and by the greatest number of competing producers, and he should therefore refrain as far as possible from inserting into his design any material or manufacturing operation which can be produced by but very few contractors, unless the use of this specialty results in a greater benefit to his client than can be otherwise obtained.

Time does not permit the citing of illustrations to cover these general principles, but I will refer to one instance related by Mr. Danforth. He called attention to the excess cost involved in the design made by an engineer for a spherical bottom tank on steel legs, as against a flat bottom tank on a steel beam floor. Mr. Danforth states the tank had a capacity of twenty to thirty thousand gallons, and in this case it is probably true that a flat bottom tank of the same capacity could be purchased for less money.

It must not be assumed, however, that this condition holds for all sizes of tanks. There is a very great saving in material brought about by the use of a spherical bottom, instead of a flat bottom supported with beams for carrying a water tank, but the saving in material is offset to some extent by the extra labor required to make the spherical bottom. The larger the tank the greater the saving in material and the less the loss in extra labor, especially if the tank is made of a size which has been adopted, by manufacturers of such overhead tanks, as standard sizes, for which they have prepared drawings, patterns, pressing dies, etc. If the capacity of the tank used by Mr. Danforth in his illustration had been one hundred thousand gallons, I do not believe any conditions would have permitted the design of a flat bottom tank which would cost less than the spherical bottom tank, except possibly the use of a very large diameter and a very low height of tank.

The point I wish to make of all this is that the independent engineer or architect should be greatly concerned with the competitive possibilities of their designs, as well as the requirements of uniformity and least weight. Many times the only way competitive possibilities can be determined is by the taking of bids on more than one design, and the adoption of a design different from the original made by the architect or the independent engineer. These latter gentlemen often take the unfortunate position of insisting that they know at all times and under all circumstances what is best for the owner and, in spite of the fact that their ignorance is exposed, do the best they can to maintain this position.

I think an engineer who permits himself to be persuaded against his best judgment, formed after full consideration of all the facts, is foolish and unreliable; on the other hand, I think an engineer who refuses to take advantage of all the facts which can be brought out and all the suggestions offered, whether or not they are different from his own solution of any problem, is likewise foolish and unreliable.

Taking up the other view of this question, namely, "Factors Affecting the Cost of Producing Structural Steelwork," I am certain that we have not the time tonight to go into this in any detail. The papers presented this evening cover quite fully many of the specific requirements. The precise information required to properly discuss this question is largely in the hands of the engineers for the fabricating companies, many of whom are here tonight, and I hope, therefore, some valuable discussion will be presented.

I will attempt only a statement of the governing principles, with a brief description of some of them. In my opinion, the governing principles are:

Uniformity of Design;
Use of Easily Obtained and Competitive Material;
Standardization of Details;
Selective Control of Shop Operations;
Technical Administration of Erection Work.

The first three principles have been covered in the papers of the evening. The fourth principle, "Selective Control of Shop Operations," has been hinted at, but not described in detail.

It is only within a short time that the larger fabricating companies have found it to be to their advantage to place the operation of the shop in charge of engineers instead of in charge of strictly practical men. Very few of the smaller fabricating plants permit engineers to have anything to do with the shop operations. The long-adhered-to idea has been that the selective control or operation program of work inside the shop must be in the hands of a so-called practical man who has served his time as a workman, and that if such a man has technical knowledge it is rather a disadvantage than otherwise. This idea grew out of the belief that an educated man was not fit to handle workingmen in a personal sense, and also from the idea that the fabricating of steel was a mystery or an art which had to be learned by long practical apprenticeship.

Engineering and technical ability have so standardized the design of structural steelwork that the operations of fabrication have become largely mechanical, and it is therefore apparent to those who have their money invested in this business that the same technical skill which standardized the design should be used to standardize the mechanical operations.

The result is the adoption of what I call "Selective Control," sometimes called "routing," and by some also "efficiency," because it forms the only logical basis for standardizing wages, or what is the same thing—standardization of production costs.

For several years the system of selective control, or standardization of operations, has been highly developed in many industries where enormous numbers of exactly similar things are produced, such as the automobile, the electrical apparatus and the agricultural implement industries. It has been considered impossible to practically apply these principles to a business like the fabrication of structural steel, where the proportion of duplicate parts is small, but it is only a matter of adopting the proper yardstick by which the standardization is to be applied.

Some excellent results have lately been obtained in this way, and there is no question that a great advance will be made along this line in the next few years. The tendency now is strongly toward the placing of this matter in the hands of engineers, and all engineers employed by fabricating companies should make it their business to study the principles of selective control and standardization of operations.

The application of the fifth principle, "Technical Administration of Erection Work," has been a slow but steady growth. It has come about largely through the necessity of the fabricating and erecting contractors, who are now often called upon to handle enormous weights, and to put together large structures within close limits of measurement and within the shortest possible time. Engineers and technical men have developed very powerful and highly efficient machinery, the proper use of which requires technical knowledge far beyond the ken of the average practical man. Efficient machinery and technical methods are being frequently employed on small jobs, and engineers have a wide opportunity to reduce the cost of erection by these means.

I notice that authors have gone quite extensively into the question of detailing and the direct relation between that work and the shop methods. They have used some illustrations which, in my opinion, may be taken in different ways. One of the illustrations used by Mr. Danforth was the old *bete noir,* the stiffeners on plate girders. Of course, it is indefensible to maintain that a plate girder stiffener should have a bearing at both ends.

In the modern structural plant, however, the stiffeners on a girder should be made absolutely identical in length. This was not done fifteen years ago, and it is not done today in a good many shops not properly equipped. In the old days the stiffener was sheared on an ordinary angle shear and possibly heeled, as it was called, on the angle shear or cut off with a cold chisel, and such methods do not produce accurate results. In a modern shop the angles are sheared approximately to the right length and each end trimmed with a special tool or milled to exact length and with ends shaped to fit the flange angles.

The only reason the stiffeners do not fit the flange angle when the girder is completed is either a crookedness of the flange angle itself, or bad holes; all of which are out of place in a modern structural shop worthy of the name. The stiffeners should be accurately made; the flange angles should be straight; and all the holes should be in the proper position, thus producing a good fit of stiffeners and flange angles.

Another thing running through this discussion is the drawings of architects and engineers from which structural steel work is to be contracted. When I first began to make drawings of that kind on my own account I had the idea that the thing to do was to make very elaborate drawings, showing every rivet to prove that I was a very competent engineer, prevent trouble with the contractor, etc. I have stopped it, because I think it is a mistake.

Any engineer who is competent to design structural steel work should be able to make specifications for his work which completely cover all detail drawings, and the best thing to do is to attach to the contract papers specifications that give the engineer control of detail drawings and shop work and then permit the fabricating contractor to make his own detail drawings. I think that is the best way to get first-class work, and usually it is the cheapest thing to do.

It may be that some clients imagine that because an engineer makes elaborate drawings he should be paid a higher fee, but I think the investors these days are beginning to learn that the man who gets results is the man who should be paid, regardless of how much time or drawing paper he uses.

If you put the work in the hands of an incompetent contractor you may have trouble, but there are not very many fabricating concerns in the United States today which make bad detail drawings. It is not worth while to encroach upon the province of the fabricating contractor who is to prepare drawings for his own shop and his own tools and methods.

I notice in Mr. Danforth's discussion he uses an illustration of knee braces with forged ends. It is true as a general proposition that blacksmith work is expensive, but when it comes to modern machinery again, it is a different proposition. If a structure contains a very large number of angle knee braces and the shop is properly equipped with heavy presses, it is more economical to bend the end of the angle or pair of angles, and probably is more accurate work, especially in light angles, than it is .o put in a gusset plate.

I mention this because it should not be considered a general rule not to design or use forged knee braces.

MR. J. A. MCEWEN:* In examining the original papers on this subject, the speaker is not quite sure of the limitations of the subject. If the consideration is to cheapen the shop work only, this could be done mainly by furnishing sections on which there is little shop work and great excess of material. Considered in this light, it would simply be folly to proceed on this basis.

Under several headings which have been brought up in the papers, we would base our remarks on the following subjects:

Design: We would say, first of all, that designing structural steel is an engineer's job, and we would also say in general that the best designs are the simplest. We find in many designs complicated systems of bracing, lattice work, etc., which begin and end nowhere. The old-fashioned three-legged strut, which we still find occasionally, is one of the best examples of this sort of thing. One of the speakers, we note, suggests using I-beams for roof construction and rafters. This is consistent within certain limitations, but we do not agree to the extent which the speaker suggests; that is, in lengths up to 30 or 40 ft. We know that, in general, for lengths over 25 ft. we can furnish trusses for main roofs and lean-tos cheaper than I-beams, and are much stiffer and are of considerable service in bracing the building. An ideal design is, of course, where all the material put in a building has at least possible work to perform. We find frequently in designs of plate girders cover plates extending full length, making additional shop work, and also constituting a waste of material. There is frequently a great waste of material in using standard connection angles, also standard bearing plates. Where these are used in great quantities, standard connections and standard bearing plates are figured as a rule for the worst possible conditions of loading for the beams on which they are intended to be used. Material should also be used to suit the conditions under which it is to be placed in the building. It has been suggested in one of the papers that a pair of angles are frequently more economical than beams and channels with separators. It might also be added that they are far more suitable for the condition from a mason's standpoint.

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Selecting Sections: First of all, we could say that there are too many sections rolled, or at least too many weights of the various sections. We believe the weights of beams and channels should be limited to one or possibly two different weights on each section. We think it would also be wise, especially in busy seasons such as we have at the present time, that the mills should discontinue rolling great numbers of sections found in the handbooks. This would simplify matters very much and enable the warehouse to carry the majority of sections really necessary. The selection of sections in designing is largely a matter of judgment and should be done only by those who are familiar with sections obtainable, and these sections should be limited in number to the fewest possible.

Specifications: In regard to specifications for structural steel work, we would say there are entirely too many of them. Many of them also have foolish clauses making shop work more expensive than necessary, such as requiring great numbers of stitch rivets in tension members, unnecessary numbers of separators, etc. Why not have uniform specifications for buildings and also for bridges? We do not see why the various engineering societies of the country do not have committees appointed to adopt uniform specifications.

Shop Details: We find in most drafting rooms a considerable leakage through expense in making up shop details. In the first place, most draftsmen have not developed a sense of economy. Foolish and expensive details find their way into the shop. A great number of unnecessary rivets are driven. A draftsman should be able also to interpret the information given in handbooks. Standard connections, gauge lines, size of rivets, etc., are given in the handbooks as a general guide. It would be impossible to give information to cover a great number of conditions entering into structural steel designs. This information is not intended to cover every case, and the draftsman should be able to determine whether special or standard details should be used. A maximum of duplication of details should be insisted upon in order to cheapen the work in the shop. A draftsman must also work to suit the conditions of the shop for which he is working, otherwise he may put them to great expense.

Shop Work: Doing the actual work in the shop in an economical manner depends upon the shop management, machinery equipment and the shop labor. At the present time the bonus system seems to be very much in favor. The writer is not an expert in this end of the business and will not attempt to discuss it. One of the things frequently overlooked in designing and of serious consequence to the shop is the designing and detailing of material in such lengths that it can be shipped economically. When single pieces of great length are required it frequently requires no little ingenuity to arrange splices, etc., so that freight will not be the most expensive item in furnishing material. The order of shipment of material is also another thing which should be given constant attention, so that the material will arrive in the field to save unnecessary expense in rehandling, etc.

Mr. R. A. Pendergrass:* The speaker agrees with the conclusions presented in both of the papers which have been presented this evening.

Both gentlemen have called attention to the importance of the design as affecting shop costs. It may be well at this time to call attention to the fact that the interest of the purchaser, the designer and the contractor are to a large extent identical, for if the engineer establishes a reputation for turning out designs which are economical from the fabricating point of view, the purchaser will obtain a lower price on his work, the engineer will encounter less friction in having the work executed and will obtain more clients, and the fabricator will obtain more tonnage, which is his great aim.

Mr. Danforth has brought up the matter of column splices. While it is true that column splices are sometimes unduly complicated, at the same time columns are frequently designed with too many splices. Several cases have come under the speaker's observation where the designer, in his endeavor to save weight, has spliced the columns at every floor. A recent example of this is a six-story building with Bethlehem *H* sections. While this is an extreme case, yet it illustrates both points, for the splices were very heavy with a large number of rivets, so that by omitting the splice at the second floor weight was actually saved. By omitting the splices at both the second floor and third floor and running the lower section through three stories, the total weight was increased only about 4000 lbs. on a total of about eighty columns. As these three story sections did not become too heavy for economical work, just think of the amount of shop work saved by the addition of these 4000 lbs. In the first place there were one-third of the number of members to handle in the yard and shop. In the second place the punching could be done much more cheaply, for with a rack punch quite a part of the cost is the placing of the piece properly in the machine for punching. Also, there would be fewer holes to punch. In the third place, there would be only one third of the number of columns to mill. In the fourth place, there would only be one-third of the number of splice plates to fit up and rivets to drive.

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*Engineer, McClintic-Marshall Co., Braddock, Pa.

Another error in designing columns is to make too many variations in the sections where this variation is small. The speaker has seen columns exactly the same except for 1/16 in. in the thickness of the web, also only 1/16 in. difference in the thickness of the flange and for only one or two columns. This not only causes expenses both in the drafting room and shop but also results in getting the material interchanged, which is very difficult to avoid where there is only 1/16 in. variation in thickness.

Another feature in the design of columns worth considering is the design of the base. Frequently the details of the base are very complicated. The speaker has in mind a recent contract having column bases requiring four different fitting and riveting operations; that is, this work had to be done in four stages. The speaker tried to get these bases simplified but was unsuccessful until he thought of using bolts instead of rivets in a certain place. This was satisfactory to the engineer and resulted in reducing the fitting and riveting operations to two.

Another feature of design complicating the shop work and which is not given the consideration which it merits, is the arrangement of the bracing of mill buildings. The speaker has seen designs of such buildings eight or ten bays long, where, on account of the bracing, there were not more than two trusses alike.

Another point in mill building design which increases the shop cost, is the providing of expansion joints. In a recent contract for a building 300 x 700 ft. the engineer had in mind to provide one expansion joint in a longitudinal direction and two in a transverse direction. It was not difficult to convince the engineer that the first expansion joint should be omitted but it was not so easy to get the other two left out. This was done however by finding out what variation in temperature was probable and then showing him that this involved less than 1/2 in. variation in the position of the column at the top and that the bending thus produced was very small. It is the speaker's opinion that in ordinary detached mill buildings, expansion joints can be entirely omitted.

Another point which has been mentioned is the use of latticed beams as girders. A number of cases have come under the speaker's observation where such a type of member has been used for rafters or purlins. This is usually wrong, not only from the shop point of view, but also from the engineering end, for lattice bars with only one rivet cannot transfer the shear. The speaker cannot refrain at this time from calling attention to the design of a large garage where latticed purlins were used for a 20 ft. bay length. These purlins were made of four light angles latticed with 2-1/4 x 1/4 in. bars with one rivet, the purlin being about 15 in. deep. It was so placed as to run over the top chord of the truss and connect to the verticals, requiring a drop end construction such as is necessary in bridge construction and with over twenty rivets in each end. The ends were strong enough to sustain a load of 150 lbs. per square ft. while the lattice would not carry 40 lbs. per sq. ft.

Another point not watched as it should be both in the design and details is in the adoption of details eliminating the punching of both legs of an angle or the flanges and web of a beam. One illustration of what the speaker has in mind will make this clearer. The design for several hundred catenary bridges showed vertical latticed trusses with knee braces at the end connecting the trusses and columns. The connection to truss was made through the horizontal leg of the bottom chord angles. By using a plate connecting to the vertical leg of these angles, the punching of the horizontal leg was entirely eliminated, saving the extra handling of about 1000 angles, varying in length from fifty to ninety feet.

While the speaker could go on for some time on this subject of design, yet time does not permit, but before passing from this subject, he would like to call attention to the unnecessary expense to which contractors are frequently put on account of being compelled to execute work from incomplete, inconsistent and incorrect designs. In endeavoring to obtain missing information on a job, he has been met with the reply that he can proceed with the larger part of the work. This overlooks the fact that the part held up may contain a number of the same sections as in the balance of the work, requiring two mill orders, scheduling the rolling at two different times, receiving the material at different times and prevents fabricating all of a similar class of work at one time. This causes the work to drag all along the line and no work can be done economically if it is allowed to drag.

In regard to inconsistent and incorrect design, it has been the speaker's observation that with such designs, trouble soon begins in the drafting room, follows the job through the shop and pursues it in the field and we are quite likely to have a job which seems a hoodoo from beginning to end.

There are one or two points in specifications which might be mentioned.

The first is the clause requiring an excess of 25% or even 33-1/3% of field rivets over shop rivets. This is an inheritance from the days when hand mauls were used for driving field rivets. The speaker would recommend that when pneumatic hammers are used the excess be either entirely eliminated or else reduced to 10%. This will save in punching, also in reaming where reaming has to be done and will also result in a considerable saving in the field work.

Another matter relating to specification is in reamed work, allowing all details not taking live load to be punched full size.

Still another point is in the eliminating of the clause requiring the planing of sheared edges in all ordinary work.

It has been pointed out that it is economical to order details in stock lengths. This practice can be facilitated if engineers will adopt a standard specification such as the *A.R.E.* specification and be satisfied with test reports. This will allow the shop to take all ordinary details out of stock.

So far we have touched upon only the design and specification. This does not mean that the importance of the preparation of the shop plans has been overlooked. This subject is such an extensive one that time does not permit going into details.

The drafting room might be called the digestive part of the fabricating body, taking the great variety of designs, I came nearly saying the raw material, and assimilating them so that the work can be easily eliminated from the shop. This requires continued alertness on the part not only of the engineer in charge, but also of all the drafting force.

This discussion has grown to such a length that it seems advisable to leave to others those features of shop planning and execution which affect the cost of fabrication.

MR. PAUL S. WHITMAN:* I wish to congratulate Mr. Pittman on his clear and concise paper covering the subject under discussion. He has covered the ground so thoroughly from a general standpoint that the only field left for discussion is an amplification or reiteration of some of the salient features already set forth.

I wish to emphasize the point made by Mr. Pittman of the importance of complete and adequate general design drawings. The average draftsman in the structural steel business is a good spacer of rivets, but nothing more. He has very little conception of the elements of design, and his ideas concerning the number of rivets required for good connections are very hazy. It is, therefore, advisable that the engineer prepare general drawings giving not only the size and arrangement of the various sections entering into the structure; but also showing the number of rivets required in all important connections. In mill building work this is particularly true of members resisting wind and crane stresses. It is vitally important for the life and stiffness of the building that the longitudinal and bottom chord bracing have adequate rivets in their connections to the main members to develop the strength of the bracing members.

Too often these connections are neglected and the draftsman concerns himself only about putting in sufficient rivets to take the dead load stresses. A riveted structure should have ample rivets in the connections to develop the full strength of the different members.

The speaker does not agree with Mr. Danforth's remark concerning an excessive number of rivets. It is far better to have too many rivets than too few. There are too many structures built with insufficient rivets owing to the fact that it is to the financial interest of the fabricator to sell the largest possible tonnage of steel consistent with a minimum amount of shop work.

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*Engineer, Riter-Conley Mfg. Co., Pittsburgh.

It is the speaker's opinion, therefore, that the general design drawings should show the number of rivets required, but the spacing and alignment should be left to the draftsman of the fabricator.

The point, however, has been well taken, that in designing steel members, the design should be of such a nature as to permit of the largest possible number of rivets being machine driven in the shop. As few rivets as possible should be placed where it is necessary that they be driven in the shop with an air-gun. This is particularly true of the basses and caps of columns. In such cases, it is usually preferable to omit the wing plates and use thicker bearing plates.

Regarding the size of rivets, it is the speaker's opinion that for ordinary building work, 3/4 in. diameter rivets should be used throughout, except in cases where extremely heavy loadings require larger rivets.

The last fifteen years have witnessed important developments in structural shop practice due to the extensive introduction of spacer punching. It has, therefore, become increasingly important that structures be designed with the largest possible number of duplicate parts. There are times when the experienced designer will find it advantageous to use a larger or heavier section than the stresses call for in order to comply with this insistent demand for duplicate parts; but each particular case must be decided on its own merits. No general rule will apply to all cases.

It is also possible to carry too far the matter of limiting the number of sections in a given structure. This is a point which should be considered in every carefully prepared design; but the choice of sections should be left entirely to the experience of the designer and not dictated by the demands of the shop management for increased tonnage.

This last thought brings me to the sentiment in that part of Mr. Danforth's paper to which I desire to take exception. He gives much emphasis to the various reasons why heavier material should be used than the actual stresses called for. While he does not definitely say so, his axiom seems to be "When in doubt use as heavy a section as your conscience will allow." While in some cases this is no doubt excellent advice, the engineer should not allow his conscience to be prodded by the before mentioned insistent demand of the shop management for increased tonnage. This demand is especially insistent when it happens that the purchaser is paying for the work on a pound price basis. No fabricator's engineer can do good designing work if he is compelled to accede to this demand.

As the majority of the steel structures of the present day are designed by the fabricator's engineer, it behooves the purchaser to make his contract in such a way that the engineer shall be given a fair chance to design a structure which will be economical for the purchaser and a credit to himself and his profession.

PROF. H. R. THAYER:* These are certainly excellent papers and worthy of the attention of every practicing engineer. The arrangement of the steel to permit of rapid and cheap fabrication demands the same care as the obvious need for economy in material.

The latter is however often slighted. Too frequently the structure comes to the engineer with every dimension predetermined, even though the steel is a large proportion of the cost. It might be that a change in the main dimensions would have given a much cheaper structure and have served its ultimate purpose just as well, but the plans were too far advanced to permit of a change.

Another evil is the common practice of designing for a fixed price per ton or on a percentage basis. Suppose that an engineer by dint of considerable effort succeeded in reducing the tonnage by 10%. His efforts would have resulted in a self-imposed fine of 10% of his fee. Nevertheless a great deal of the steel in this district is designed on that basis. It would seem to the writer that a certain lump sum based on an estimate would be much fairer.

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*Assistant Professor Structural Design, Carnegie Institute of Technoogy.

Coming down now to the question of details, Mr. Danforth mentioned the matter of gussets. No doubt one might get along without stiffeners by making it a sixteenth thicker. But would the plate so thickened be as strong as with the stiffeners? Would not the additional rigidity be well worth the additional cost?

In the past twenty years the writer has heard and participated in many discussions as to relative strength of different designs and methods of computing them, often with very little satisfaction. In his opinion these and many other questions should be settled by a series of comprehensive tests.

MR. J. E. BANKS:* A new draftsman must be considered as a new man who has to be taught and he should be taught fairly early that there is something beyond the edge of his drawing board. He should be urged to go down into the shop and see his work passing through it. This is not difficult, especially in a small shop. It is also advisable to have the squad engineer go out along with his men toward the finishing of an erection job of his design. The speaker did that for a number of years with quite a good deal of profit to his men. You can always see, toward the end, any difficulties that may have arisen due to design.

The first thing of importance, of course, is the general design. There are some consulting engineers, who seem to have had no experience in detail design. The experienced draftsman can tell in five minutes whether or not the plans before him were made by a man with any experience in the detail drawing room. I remember one job where we had 6 in. beams connecting into the webs of 6 in. columns, a 6 in. leg connecting angle on each side!

It was part of the speaker's work for several years to get up bulletins for various drawing rooms that might help in the way of broadening the imagination, and in the avoidance of errors. I think some of you who have to teach your draftsmen might profit by doing something of the same kind. A paper could be gotten up, manifolded and passed among your men.

*Engineer, Bureau of Standards, American Bridge Co., Ambridge, Pa.

The man who is worthy of a place in the drawing room or anywhere else in the work, from the contracting to the erecting, ought to be a man who has the whole course in his mind with the thought of the advantage to his company.

MR. T. J. WILKERSON:* Throughout the papers and discussions tonight the structural steel buildings rather than bridges has predominated and as my recent experience has been principally the latter I feel that what I might say will not apply to buildings in every respect.

Just as Mr. Pendergrass has said there are designing engineers who do not know what they want and cannot be told, such engineers make the work more expensive. Many times while connected with manufacturing plants I have seen expensive details designed by reputable engineers when a little study would have simplified these details and reduced their cost.

In regard to the drafting room work I was very much impressed with the unnecessary erection cost on some work recently erected in this city. This work had very heavy columns with relatively light gusset plates for the longitudinal bracing riveted thereto. In nearly all cases these plates were badly bent in shipping and handling the columns. I took occasion to analyze this condition and found that had the plates on one side been shop riveted to the horizontal streets and those on the other side to the diagonals, not only would the plates been less liable to injury but the erection would have been easier and the number of field rivets would have been reduced. I, therefore, think it would be advisable for the shops to send their drafting room squad bosses out on erection so they can become familiar with the difficulties of the erector and ascertain why erection is so expensive.

I do not believe that the reduced engineering and drawing room costs has reduced the production cost of the work but if anything has increased it as the loss in using incomplete drawings in the shop and field I believe is greater than the cost to prepare the drawings.

As to what Mr. Duff has said about drawings, I think the designing engineer should prepare complete stress sheets giving thereon all stresses and make-up of members of the structure and such general drawings as are required to give the drawing room complete and correct information as to what he wants, then allow the fabricating plant to prepare the details in line with their standard practice. Later the engineer should carefully check the details to satisfy himself as to their strength and adaptability.

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*Division Engineer of Bridges, Bureau of Engineering, City of Pittsburgh.

MR. E. J. UHL:* I have listened to the discussion with a great deal of interest and pleasure. One thing that impresses me very much about Mr. Danforth's paper was the question that Mr. Duff brought up about stiffeners on plate girders. It is not always by following cheap methods that a concern profits most. When we have for consideration a customer that buys this class of work more than once and who employs competent engineers to pass on it, the effect of good workmanship greatly influences future sales. We all know that it is more pleasing to the eye and more nearly correct to make all stiffeners on plate girders to come to a full and even bearing where they come in contact with the flanges. The past experience of the Memphis Steel Construction Co. has borne this out.

MR. GEO. W. NICHOLS:* The factors entering largely in determining the cost of structural steel have been well considered in the papers as presented by Messrs. Pittman and Danforth. There are, however, a few remarks which I might add toward the discussion of their papers.

In the design of any steel structure, considerable care should be used in the preparation of the general drawing, which is to be used by the various steel concerns in preparing their bids. This drawing should be clear in every respect and as definite as possible; so that the estimator will not find it necessary to add to his bid a certain amount to provide for the worst condition which might arise, and which he might be compelled to meet in case he should secure the contract. This is where money can be saved, as the bidders are bidding on the same general construction and bids will be more consistent; therefore, too much emphasis cannot be laid on this point. In the case where many columns are used, detail should be given for base, splices and caps. The same is true for other connections and special framing.

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*Chief Engineer, Memphis Steel Construction Co., Greensburg, Pa.

*Engineer, S. C. Webb Engineering Co., Oliver Bldg., Pittsburgh.

It is always well to reduce to a minimum blacksmith work on structural details; as a rule, this class of work is slow in coming through the shop, and will of course tend to hold up the completion of certain work, which, if care had been exercised by the designer, possibly built-up sections could have been used; this is illustrated in the case of bent knee brace angles, where plate and angles should have been used. This may take more material, but as mentioned by the writers of the papers this evening, it will pay to do it. In the structural business, like most others, money is to be made by keeping the steel on the move.

Box sections which require backing-up of rivets from inside should never be designed, if it is possible to eliminate them. Built-up sections which permit of painting and caring for structure, should be insisted on, especially on steel work exposed to weather conditions.

It is well to avoid right and left hand pieces where possible; furthermore, where it is possible to punch a few extra holes in pieces, this should be done rather than complicate the shop work as well as field work in having rights and lefts.

One item which oftentimes increases shop costs is lack of necessary information on detail drawings; it is well to adequately cover this item for template makers' use and in assembling the structure.

MR. GEORGE H. DANFORTH:* Mr. Duff commented on the round bottom tank. He is absolutely right, but the designing engineer nine times out of ten makes the radius of his tank bottom, whatever, in his inner consciousness, he thinks best, which means special formers to get out his work, which adds to the expense.

As to the stiffeners, I will confess that I raked that out of the past for a purpose, and that purpose was that the question is still with us. It may be 40 or 50 years old, but it is still here.

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*Author's closure.

If a shop is equipped to mill off the entire end of the stiffener so that it forms a distance piece for the flange angles, then Mr. Duff is perfectly right; but nine out of ten shops are not so equipped. With them, it is a question of shearing the stiffener to length and "heeling" the ends to clear the fillet of the flange angle.

As far as design drawings go, there was a certain architect in Chicago who had a reputation all over the United States. His drawings came out about as quick and as complete as any drawings I ever saw. He had the force and the data and the leadership to bring them out. And when you came to detailing from his drawings, there was no question as to what he wanted. You could see it and figure accordingly. I am inclined to think, therefore, that detailing within certain limits is a good thing.

Regarding the matter of forged knee braces, that like the stiffeners, is a question of equipment. With 500 to 1000 knee braces to make, there is no question but that the forged knee is the cheaper because you have enough quantity to spread the cost of making the necessary dies and your total cost would be less than the method to which Mr. Nichols referred, of using two clips and a gusset plate at each end.

Mr. McEwen commented on the beam roof. The beam roof is a great thing for a good many places, but there are places where it does not apply. Not more than 75 miles from Pittsburgh, there is a building 150 ft. wide and 240 ft. long biult entirely out of beams except for the interior columns. The good features of that beam roof—the job being let on competition—so impressed the owners that they paid a good bonus to get that beam roof rather than a lighter riveted truss design.

In regard to the matter of beams and channels in only one or two weights, nobody wishes that more than I do, but I do not think I will ever see it. The rolling mills of this country, for the last ten or twelve years, I think, without exception, have picked from the shapes they made and have indicated in some way in their various handbooks, by asterisk or otherwise, the sections they urge used. Yet within the last two weeks I have seen a firm of engineers in good standing throughout the country, call for such a monstrosity as a 15 in. 90 lb. beam. Comment on that is not necessary.

As to uniform specifications, I would like to see uniform specifications, but I do not think that I will live long enough to see them. When you begin to talk of specifications, you come to the matter of personal equation, and it is the personal equation of the men who count. We all have our own ideas, notions and opinions and some of us like to have those notions, ideas and opinions given a little weight. Not so very long ago I was interested in a job that was let under a specification calling for soft open hearth steel. After is was let, it developed that a small portion came under the jurisdiction of another man, who specified medium open hearth steel for his little piece. Now there was no earthly use in specifying medium steel in one place and soft open hearth in another, yet that was his idea and that was in his jurisdiction and he wanted it. When you consider that soft open hearth steel runs from 56 000 to 64 000 and medium open hearth runs 60 000 to 70 000, you will see that it is possible to get a material that would meet both specifications, and that is probably what he will get.

There is one other little matter relating to simplicity of design. I have been able to watch the mental operations which results in the design of a building a good many times, and roughly speaking, designers are divided into two classes; the man who looks out for the stability of the building first and then adapts his architectural design to the question of stability, and the other is the man who creates in his imagination his building regardless of stability, and then requires his unfortunate engineer or contractor to get in around, over or under in some way the sacred architectural lines and make the building stand up. As a result, you will find buildings where there is not a single column that runs through from the cellar to the roof. They will be offset anywhere from an inch to ten or fifteen feet. That is not good design, nor is it good practice. There are, of course, occasions where it is necessary to offset columns, but these ought to be reduced to a minimum.

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ENGINEERING PHASES OF SMOKE ABATEMENT

By OSBORN MONNETT*

If I were to answer the question, what are the three most important things in smoke abatement, I would be tempted to say, first, draft; second, *draft;* and third, DRAFT. Draft is necessary to the smokeless burning of high volatile coal. We must have oxygen; by the draft we get the oxygen in over the fire where the volatile is being distilled. In investigating the smoke problem in Chicago it was found that draft was so important as to overshadow every other consideration and through a long series of investigations covering some thousand separate and distinct studies of boiler settings a curve was developed which tells us how much draft we need for different rates of combustion. Roughly the rule is this. We need 0.01 in. draft over the fire per pound of coal burned per square foot of grate surface per hour. That tells the story almost entirely throughout the range of the curve. Beginning with 0.15 in. of water over the fire we are able to burn 15 lb. of coal per sq. ft. of grate surface per hour smokelessly. Cases can be cited where 0.15 in. has burned 20 and even 25 lb. of coal, but it did not burn it smokelessly.

The limit rate of successful smokeless operation for hand fired units is about 28 lb. of coal per square foot of grate surface per hour. Above this point reliance is placed on mechanical stokers. You will note the draft required follows the rule almost exactly in the lower rates. When we get to 0.5 in. over the fire we can take care of only about 40 lb. satisfactorily. This relates more especially to Illinois (free burning) coal.

The rate of combustion in any plant is fixed first by the load. When the load is known, fix the ratio of grate surface to

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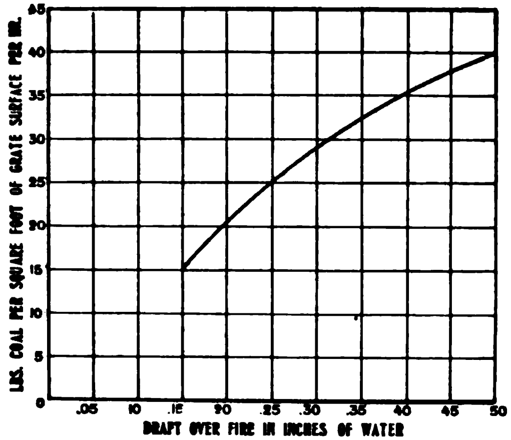


DRAFT FOR SMOKELESS COMBUSTION

Fig. 1.

heating surface. These two factors decide the rate of combustion. Having this, we are able from the curve to judge how much draft we need over the fire.

On return tubular boilers a ratio of heating surface to grate surface of 40 to 1 works out very nicely. With mechanical stokers the ratio of 50 to 1 is standard. For water tube boilers in Chicago practice, we ask for a damper ratio of 4-1/2 to 1; that is, the grate surface connected with the boiler is 4-1/2 times the free opening in the damper. The ratio of grate surface to breeching may be as 5 to 1, that is the actual free opening in the breeching has a ratio of 1/5 of the actual connected grate surface. Then the total connected grate surface to stack works out in the same ratio, 5 to 1, that is, the area of the stack should show a free opening of 1/5 the total connected grate surface. This holds good for the average height of stack. These ratios are more liberal than found in ordinary practice, but the plant with the liberal ratios is the plant that is getting away from the smoke and carrying the load.

In laying out the stack for any plant it is necessary to know how much draft loss there is in the particular type of boiler setting selected so as to know that the proper amount of draft over the fire will be provided. This loss runs from 50 to 65 per cent of the draft available at the stack side of the damper.

Allow about 0.1 in. draft per 50 ft. of breeching and 0.05 in. draft for every additional boiler over one connected to the breeching, because of the inrush of gases having a choking effect on the boiler farther from the stack; if the boiler happens to be dead we have an inrush of cold air which has the same effect. After getting the draft required in this way at base of stack, dividing by constant K, determines the height of the stack in feet. This is the standard formula published some years ago by Stirling, and it has worked out very nicely.

$$D = 0.52\ H \times P\left(\frac{1}{T} - \frac{1}{T_1}\right)$$

in which

D = Draft in inches of water
H = Height of stack in feet
P = Atmospheric pressure
T = Atmospheric temperature (absolute)
T_1 = Temperature stack gases (absolute)

$$K = 0.52 \times 14.7\left(\frac{1}{T} - \frac{1}{T_1}\right)$$

TABLE NO. 1

Temperature Stack Gases	K
750	0.0084
700	0.0081
650	0.0078
600	0.0075
550	0.0071
500	0.0067
450	0.0063
400	0.0058
350	0.0053

In analyzing stack temperature conditions in a great many plants, it was found that the average gas temperature in the stack is 418°. That seems rather low but was obtained from fifty different plants in commercial operation with all kinds of equipment. Five hundred degrees is more likely to be the breeching temperature than the stack temperature as we are losing heat all the way along.

In studying the smoke problem in Chicago, it was soon realized that in order to make any kind of a showing, it would be necessary to develop some type of hand fired furnace that could be operated within the smoke limits. Ninety per cent of all the boilers installed are horizontal return tubular boilers and they make a large percentage of the smoke of the average city. The old standard Hartford setting consisted of a low setting with about 24 in. from the dead plate to the sheet, a plain bridge wall and shallow combustion chamber, small damper and everything unfavorable to smokeless operation. Thousands of these settings had to be cleaned up.

The first attempt to make such a setting smokeless was to spring a deflection arch behind the bridge wall, the idea being to break up the rush of volatile matter and cause it to go under the arch and pass into the combustion chamber. It was nothing but a makeshift. The next step, one that was developed about 1896, was the old McGinnis arch setting, consisting of two single spans of arch work, one behind the bridge wall and the other over the grate, the idea being to use the coking method of firing and carry the volatile matter down under this arch and impinge on this deflection arch at which time it would be pretty well mixed with air and consumed. This setting, when used with rates of combustion not higher than 15 lb. of coal per square foot of grate surface, worked out very satisfactorily when carefully attended to. But it depended on the fireman to such an extent that in 1907 when the engineering department was reorganized it was not considered a satisfactory setting.

At this time the authorities were all agreed that the Dutch oven was the best thing in smoke abatement. A great many of these Dutch oven furnaces were installed. The objections to the Dutch oven were that it took up so much floor space; was

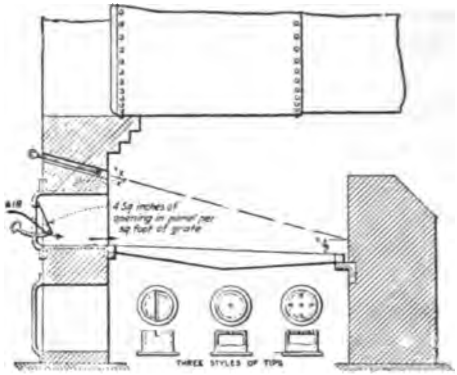


Fig. 2. Siphon Type of Steam Jet

Fig. 2.

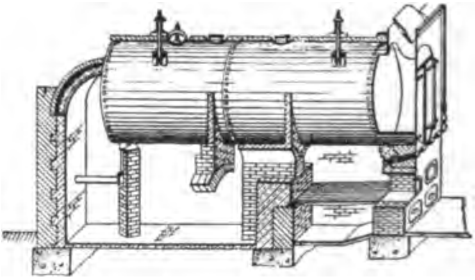


Fig. 3.

excessively high in first cost; and also high in maintenance. It took a high head room to get it under the boiler and the objections were so strong that the department finally took to installing semi-extension Dutch ovens.

Finally, they came to flush front Dutch oven settings. All these Dutch oven settings were failures. They made more smoke than the standard Hartford setting. The reason for this was rather obscure for some time, but finally it was reasoned out in this way. When you throw high volatile coal on a fire there is a normal distillation of volatile matter due to the heat of the fire. But when you throw coal on a fire with a Dutch oven you get not only the normal distillation of volatile matter but you also get an artificial distillation due to the high temperature of the heat radiating from the red hot fire brick over the fire resulting in a double distillation of volatile matter, and it causes dense smoke in spite of all efforts to prevent it.

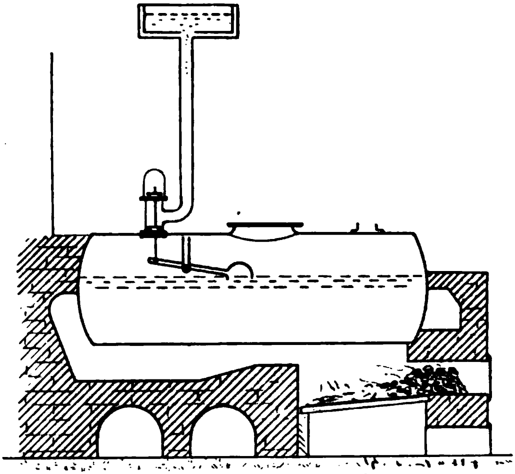
Finally, by taking off the brick work over the fire, a smokeless furnace was obtained. This reduced the rate of volatile distillation because there was no radiation of heat from the red hot fire brick. It also increased the steaming capacity of the boiler because there was a direct radiation from the grate into the boiler. Thus we account for three things necessary for perfect combustion; temperature, in zone of high temperature back of bridge wall; oxygen, which we get in through paneled doors; and air syphon steam jets, and a mixture against the bulk head wall over the deflection arch. A setting finally adopted for standard in the department is the double arch bridge wall setting shown in Figure 3. In handling such a setting the alternate method of firing is best.

There are some few points regarding operation to which I would direct your attention if the best results are to be expected from hand fired furnaces. The ordinary method of firing a new boiler is to build a fire with kindling and throw in a lot of fresh coal. This makes a great deal of smoke. By firing from the top and covering the clean grates with green coal to a depth of 4 or 5 inches and then building a fire at the bridge wall with kindling or live coals, it is possible to get up steam without violating the smoke ordinance. The volatile matter from under the fire has to pass up through a high temperature zone and becomes consumed.

Another proposition is cleaning of fires. The ordinary method is to rake out one side, wing over a lot of live coal and fill up that side with fresh coal. This again makes smoke. If one side is cleaned out and the grates covered with green coal and then red hot coal thrown on top of the green coal, it is possible to clean a fire without smoke. This method is being used here in Pittsburgh in firing locomotives with great success at the 28th Street Yards of the Pennsylvania Railroad, Lines East.

Another phase of this hand-fired proposition is the burning of coal at low rates of combustion, for heating plants. This is really a harder problem than that pertaining to high pressure work. We have poorer firemen, less draft and everything is against successful operation.

Studying the progress made in burning coal at low rates of combustion takes one back to the time of James Watt in 1769. We started to experiment with the coking method of firing as we know it today, but discovered right away that it was the human element in hand fired units which really decided the proposition. A good fireman as soon as he finds out that he is a good fireman graduates into a second or third rate engineer. We have lots of engineers but very few real firemen.



Watt's Furnace showing coking method of firing.

Fig. 4.

MINIMUM HEADROOM REQUIREMENTS FOR SMOKELESS SETTINGS

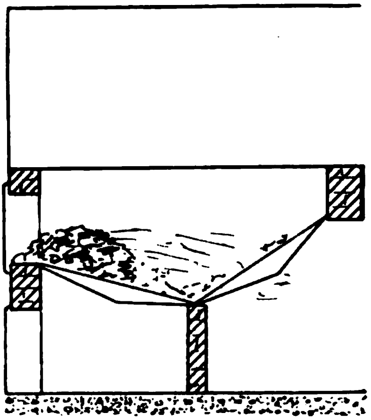
BOILERS

Furnaces	Horizontal Return Tubular				Water Tube				Continental or Scotch Marine
	54"	60"	66"	72"	Hor. Baff 1 ft. 1½ in. Pitch	Vert. Baff 1 ft. 1½ in. Pitch	Hor. Baff 3¼ in. Pitch	Vert. Baff 3¼ in. Pitch	
	‡‡	‡‡	‡‡	‡‡	Front	Header	To	Floor	
No. 6	32"	34"	34"	36"	6'–0"	*	6'–6"	*	**
No. 7	36"	40"	40"	42"	†	†	†	†	**
No. 8	32"	34"	34"	36"	6'–0"	*	6'–6"	*	**
	§	§	§	§					
Down Draft	60"	60"	60"	60"	6'–0"	*	6'–6"	*	*
McMillan	52"	54"	60"	60"	6'–0"	*	6'–6"	*	**
Twin Fire	58"	60"	62"	64"	6'–0"	*	6'–6"	*	*
Semi Ext. Refuse Burning	††	††	††	††	7'–0"	*	7'–6"	*	*
Burke	48"	48"	50"	54"	5'–0"	*	5'–6"	*	Full Extension
McMillan	48"	48"	50"	54"	5'–0"	*	5'–6"	*	Full Extension
Chain Grate	72"	72"	78"	78"	7'–0"	9'–6"	8'–0"	10'–0"	**
Moore	48"	54"	60"	60"	6'–0"	8'–6"	6'–6"	9'–0"	**
Roney	60"	60"	60"	72"	7'–0"	9'–0"	7'–6"	10'–0"	**
20th Cent	54"	60"	66"	72"	7'–0"	9'–0"	7'–6"	10'–0"	**
Detroit	66"	72"	78"	84"	7'–6"	9'–6"	8'–0"	10'–0"	Full Extension
Model	66"	72"	78"	84"	7'–6"	9'–6"	8'–0"	10'–0"	" "
McKenzie	66"	70"	70"	70"	7'–6"	9'–6"	8'–0"	10'–0"	" "
Murphy	66"	72"	78"	84"	7'–6"	9'–6"	8'–0"	10'–0"	" "
	‡‡	‡‡	‡‡	‡‡					
American	42"	42"	42"	42"	6'–0"	8'–0"	7'–0"	8'–6"	**
Jones	36"	38"	40"	42"	6'–0"	8'–0"	7'–0"	8'–6"	Min. Diam. of furnace 36".
Riley	**	**	**	**	7'–0"	8'–6"	7'–6"	9'–0"	**
Taylor	**	**	**	**	7'–0"	8'–6"	7'–6"	9'–0"	**
Westinghouse	**	**	**	**	7'–0"	8'–6"	7'–6"	9'–0"	**

Notes:—

*—Combinations not recommended as smokeless settings.
†—Not adapted to water tube boilers.
††—Applied only to water tube boilers; No. 8 better for H.R.T. Boilers.
**—Combinations not ordinarily met with in practice.
‡—Exceptionally wide settings will need more headroom to take care of extra spring of arch.
‡‡—Shell to Dead Plate.
§—Shell to Floor.

In 1785 Watt made an improvement on his coking method of firing by incorporating a magazine feature, keeping the magazine full and charging the furnace by shoving through with a slice bar. In 1804 Wolf put another feature in his system in the dumping grate bar which we have even today. It made a complete system of burning coal with a low rate of combustion with a minimum amount of smoke and incorporated the magazine feature. This was the first attempt to do anything of that kind.

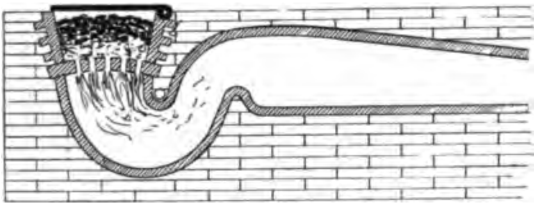


Clark's Furnace
1850

Fig. 5.

The idea was good and inventors kept trying to improve on the methods. In 1838 Rodda built a bulkhead over his fire, causing the volatile to pass through the fire, but burned out the grates. In 1850 Clark divided his furnace into two, front and back, with a bulkhead in the ash pit. This also burned out rapidly and was not feasible.

Fairbairn in England in 1860 passed the volatile matter down through the fire. He had the germ of the down draft idea as we know it today. A water cooled grate made the down draft boiler permanent and it is now standard equipment for



Fairbain's Down Draft Furnace 1860

Fig. 6.

heating work. There is danger of making smoke in a properly operated down draft furnace, because when sliced it is through a zone which has already given up its smoke forming matter, being all red hot coal from which the gases have passed away. Charging such a furnace does not disturb the fire and, therefore, can be done without danger of smoke (see Fig. 7).

Passing to the mechanical stoker, I will characterize the settings as horizontal and vertical baffle systems. The horizontally baffled system I will dismiss in a few words. In a nut shell, the horizontally baffled furnace is a fool-proof proposition and any stoker combination can get smokeless results provided draft is available. The only head room required is that necessary to get the particular type of stoker under the boiler selected. The vertically baffled water tube boiler is the proposition that requires careful thought.

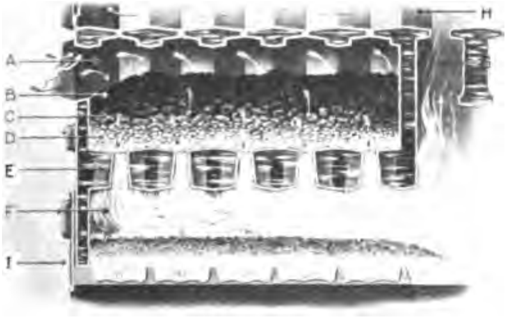


Fig. 7.

DISCUSSION

Mr. O. P. Hood:* I want to express my appreciation of this talk by Mr. Monnett, which is the result of so much experience. Some of us put up a few boilers, but to talk of boiler settings by the hundreds and thousands, there are very few engineers who have had the opportunity Mr. Monnett has had. I have nothing to add, except, perhaps, to answer the question that was asked as to whether these figures, which were probably worked out with Illinois coal, are just as good for Pittsburgh coal. Some investigations of the Bureau of Mines along this line may be interesting. Six or eight years ago a board of engineers was gotten together to advise what was then the Geological Survey as to what lines of investigation the government should take up that would be really helpful. The Board propounded the problem, to find out whether it was possible to design furnaces in a rational manner, rather than by rule of thumb; that is to say, is it possible to take coals of different analyses, coming from different parts of the country, and by proper computation, design a furnace to fit those particular coals?

It is needless to say that when we build a bridge we have loads and stresses to begin with. Mr. Monnett's work tonight impresses us as the result of very extended experience, rather than rational figuring, which might be applied to other fuels as well.

Mr. Kreisinger is in the room and he can tell us what results he obtained with three coals, Pocahontas, Pittsburgh and Illinois, all burned in the same furnace under the same general conditions at rates varying all the way from 10 to 15 lb. per sq. ft. per hour up to 60 or 70 lb.; this in an effort to discover how much combustion space is needed to reduce combustible gases down to, say 2 percent. The work of the Bureau of Mines in that line was finished a little while ago, and the manuscript is in the hands of the printer.

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*Chief Mechanical Engineer, U. S. Bureau of Mines, Pittsburgh.

MR. H. KREISINGER:* I can give here only in a general way the results of the experiments referred to by Mr. Hood. The complete data relating to these investigations can be found in the Bureau of Mines' publications, entitled "Combustion in Fuel Bed of Hand Fired Furnaces" and "Combustion of Coal and Furnace Design."

The combustion investigations were made in a furnace equipped with a side feed Murphy stoker and provided with a combustion space about 40 ft. long and, on the average, 3 ft. by 3 ft. in cross section. At the end of this combustion space the furnace gases were discharged under a Heine boiler. Along the path of gases through this long combustion space were inserted water-cooled gas samplers at space intervals of about 5 feet. In order to reduce the error, due to stratification of gases, four to nine samplers were used at each of these cross sections, so that about 70 gas samples were collected simultaneously. The analyses of these samples furnished the necessary data to study the process of combustion along the path of gases. The object of these investigations was to determine how much combustion space is needed to obtain any desired degree of completeness of combustion, when the kind of coal and the rate of combustion is given.

The results of these investigations show that only 6 to 7 lbs. of air per pound of coal burned can be forced through the fuel bed, no matter how fast the air is supplied. The faster the air is supplied, the faster the coal in the fuel bed burns or gasifies, the ratio of the weight of air to the weight of coal gasified remaining very nearly constant for all rates of combustion. This is true when the fuel bed is level and free from holes, and about 6 in. thick. The gases rising from the fuel bed contain no free oxygen and 20 to 30 percent of combustible gases, besides large quantities of tar. The combustible content is the result of distillation of the volatile matter and of the reduction process of CO_2 to CO. All of this combustible must be burned in the combustion space. If this is not done smoke is produced and a large part of the fuel is wasted. The question of a proper size of combustion space is, therefore, a very important part in the problem of designing smokeless furnaces.

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*Engineer, U. S. Bureau of Mines, Pittsburgh.

Inasmuch as the gases rising from the fuel bed contain no free oxygen and a large percentage of combustible, a sufficient quantity of air must be supplied over the fuel to make complete combustion possible. The quantity of air which must be thus supplied varies from 7 to 12 pounds per pound of coal fired. It should be introduced into the furnace in small streams as close to the fuel bed and at as high a velocity as possible to facilitate its mixing with the combustible. As the mixture flows through the combustion space, the combustible burns and the gas analyses of the samples taken at the successive sections of the path of the mixture show diminution of the percentage of combustible and an increase in the products of complete combustion. If the percentage of combustible is plotted as ordinate and the length or volume of the combustion as abscissae, we obtain a curve shown in Fig. 8, which gives the relation between the completeness of combustion and the size of the combustion space. The drop of the percentage of combustible is very rapid at first, but becomes

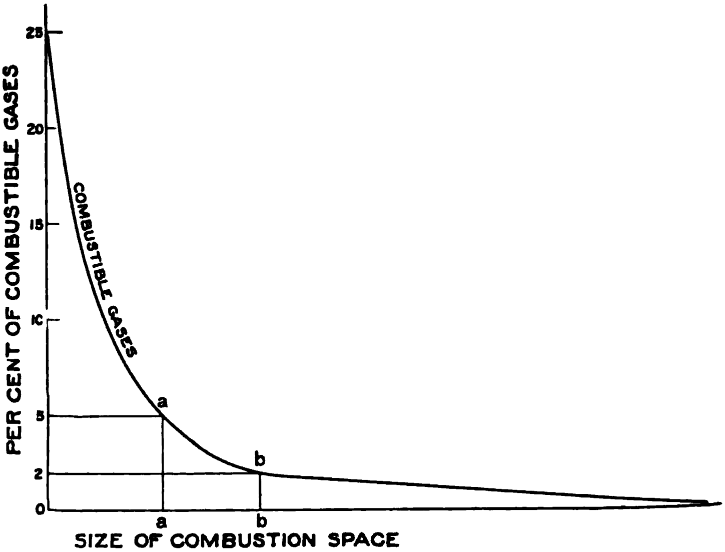

Fig. 8.

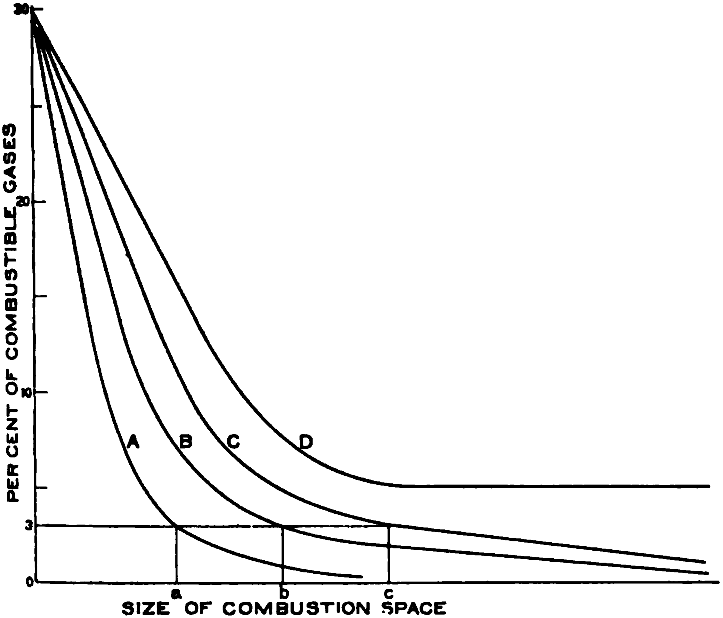

Fig. 9.

slower and slower as the mixture flows farther away from the surface of the fuel bed. For any given fuel, the rate of combustion and air supply we get from this curve a relation between the completeness of combustion and the size of the combustion space. Thus, if we are satisfied with a combustion leaving 5 percent of unconsumed gases, we need a combustion space represented by the length of the abscissae from *o* to *a*. If, however, we want the combustion complete within 2 per cent, we must have a combustion space represented by the length *o* to *b*, and so on. In other words, with the given conditions we can obtain any completeness of combustion by providing the furnace with certain definite size of combustion space.

The curves in Fig. 9 represent the type of curves obtained when experimenting with different rates of combustion, different kinds of coal, and different percentages of excess air.

With any given coal, if we keep the excess air constant, but make the rate of combustion 20, 40 and 60 lbs. per sq. ft.

per hour, we get three curves having the relative position shown by *A, B,* and *C*. The required size of combustion space for the same completeness of combustion of, say 3 percent of these three cases would be *oa, ob,* and *oc,* respectively.

Again, if we keep the rate of combustion and the air supply constant but use the three kinds of coal, Pocahontas, Pittsburgh and Illinois, we get three curves similar to *A, B,* and *C,* and the size of combustion space required for a completeness of combustion of 3 percent will be *oa, ob,* and *oc,* respectively. It was found that the required size of combustion space for these three coals was not proportional to the percentage of volatile matter, but very nearly proportional to the percentage of oxygen in the dry coal; that is, the ratio of the combustion space was 3, 5 and 9, respectively. Whether this is a mere coincidence or not can not be stated at this time.

If we keep the same fuel and the same rate of combustion, but make the air excess 75, 50 and 25 per cent, we again obtain three curves similar to *A, B* and *C*. The size of the combustion space required to obtain complete combustion to within 3 percent will be *oa, ob,* and *oc,* respectively. If the air supply is below that theoretically needed, the combustion is never completed no matter how large the combustion space is; this combustion process may be represented by the curve *D*. In general, the smaller the excess of air the larger must be the combustion space for the same completeness of combustion. Conversely, within certain limits, the smaller the combustion space the larger must be the excess of air. So that for each furnace there is with a given fuel and given rate of combustion one definite percentage of excess of air which gives the best results. This most economical percentage of excess of air is different for different rates of combustion and different fuels, when used in the same furnace.

The admission of air into the furnace is practically uniform in all cases. If the feed of coal is uniform, as is the case with most mechanical stokers, it is comparatively easy to adjust the air supply to obtain the best results. With a hand-fired furnace the case is different; the supply of air is nearly uniform, but the feed of coal is intermittent, so that an exact adjustment of the air supply is practically out of the question. Although two or three minutes after firing the air supply may be 75 or 100 percent in excess of the theoretical amount needed for complete combustion, during the first minute immediately after the firing it may be 30 percent below it. Before the firing the combustion process follows a curve like *A*, and for a short period immediately after the firing it follows a curve like *D*. So that during successive firing cycles the combustion processes fluctuate continually between the curves *D* and *A*. Immediately after firing we have incomplete combustion and smoke, due to insufficient supply of air; two or three minutes after firing we have large excess of air and a clear chimney. These conditions grow worse, as the firings are farther apart and larger quantities of coal are fired at a time. On the other hand, small firings at frequent intervals make it possible to get enough air into the furnace immediately after the firing to obtain complete and smokeless combustion, without having a very large excess of air and its accompanying losses before the firing. Small and frequent firing brings the two curves A and D together so that nearly complete combustion for both curves is possible within the available combustion space.

In hand-fired furnaces under power plant boiler smoke is made at the surface of the fuel bed. It is not made by the combustible gases striking the cooling surfaces of the boiler; this merely stops their combustion. The smoke is made at the surface of the fuel bed because the volatile matter, which is driven off as heavy hydrocarbons in the form of tars, is heated rapidly in entire absence of oxygen. This rapid heating causes these hydrocarbons to break into soot and hydrogen, and by reaction with CO_2, into CO. Five feet from the surface of the fuel bed the combustible gases consist mainly of CO and H_2; there is only a very small trace of methane and no heavy hydrocarbons which might produce soot by decomposition. If sufficient oxygen were supplied at the point of distillation, the heavy hydrocarbons which are distilled from the coal would burn without first decomposing into soot.

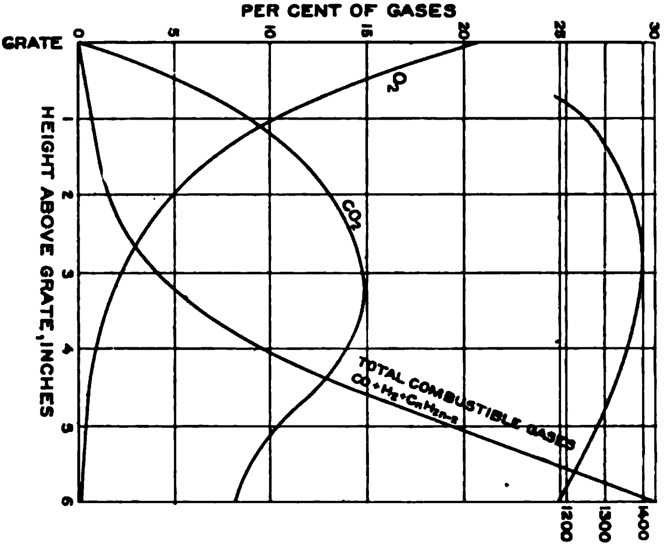

Fig. 10.

If the fuel bed is level no oxygen goes clear through it, even if the bed of hot coal is only 5 inches thick. The oxygen is all used up in combustion before the air coming up through the grate reaches the top of the fuel bed, where the volatile matter is distilled from the freshly fired coal. The process of combustion in the fuel bed of a hand-fired furnace is shown in Fig. 10. The curves have been determined experimentally by sampling gases at various distances above the grate. The curves show that the oxygen disappears about 3 to 4 inches from the grate. At this same level the CO_2 content reaches a maximum of about 15 percent, and the CO which up to this point was present only in small quantity commences to rise rapidly. Beyond this plane the CO_2 drops, showing that a reducing process is taking place. At the surface of the fuel bed the CO_2 content is about 8 percent, and the total combustible, consisting mostly of CO, is about 30 percent, with no free oxygen to burn it. The temperature in the fuel bed follows somewhat the curve of CO_2. There are, then, at the surface of the fuel bed, two very favorable conditions for the formation of smoke; high temperature and a reducing atmosphere.

The combustible gases rise from the fuel bed in one large stream, and the additional air is supplied to the outside of it. If this air is supplied in large volume at low velocity, the stream of combustible gas and the stream of air are apt to flow a considerable distance parallel to each other without mixing, and the combustion occurs only where the two streams come in contact, and is necessarily slow. If, however, the air is supplied in a large number of small streams at high velocity, the streams of air penetrate the large stream of combustible gases, violent mixing takes place and the combustion is rapid, and may be nearly completed before the gases leave the combustion space.

We may then say, that for best results the air should be supplied in sufficient quantity to insure complete combustion. It should be introduced as close to the surface of the fuel bed as possible in order that the volatile matter may burn without first decomposing into soot and light gases, and to make as much of the combustion space available for mixing and burning as possible. The air should be introduced in a large number of small streams at high velocity to promote mixing and make the available combustion space more effective.

These are the reasons why Mr. Monnett named draft three times as the three things necessary to obtain smokeless combustion. Draft is needed to supply a sufficient amount of air into the furnace; draft is needed to introduce the air in a large number of small streams and at high velocity to accomplish good mixing, and draft is also needed to overcome the resistance of mixing arches or other structures that are designed to improve mixing. If I were asked to name the three most important factors in obtaining complete and smokeless combustion, I would say this:

(1) Supply a sufficient amount of air to obtain complete combustion;

(2) Supply the air as near to the surface of the fuel bed as possible; and

(3) Supply the air in a large number of small streams and at high velocity.

These factors are stated in more definite terms than Mr. Monnett's three drafts, although virtually meaning the same thing, because draft is needed to produce all of them. In the ordinary boiler room we can not measure the air supply, and we can not measure the intensity of mixing. Although the draft is a very poor measure, indeed, of these factors, nevertheless it is a measurement that can be made easily in any boiler room.

Mr. H. D. Stratton:* With the boiler designed for normal load, what effect would it have on the smoke if the boiler only ran at half or three-quarters' load?

Mr. Monnett: If you get your rate of combustion too low on a plain grate, it is difficult to keep down smoke. Smoke prevention on high pressure hand-fired units depends upon keeping the brick work hot. At the same time it works out fairly well, because when the rate of combustion is reduced the periods of firing are further apart and you can adopt the coking method of firing. I speak more especially of Illinois coal. I never personally fired such a setting with Pittsburgh coal.

I might say, in reference to hand-fired units, that there is a rather fixed limit, 150 h.p. is about the largest unit that ought to be hand fired, although in Chicago we never limited it to that. We have units up to 350 h.p.; but the city of Cincinnati specifies in its ordinance that no unit above 150 h.p. shall be installed without some type of mechanical stoker. Mr. Frank, of the Pittsburgh Department, informs me that in the Pittsburgh District 100-boiler horse-power would be the limit for a hand-fired unit in the future. I believe this is a step in the right direction, because of the puffy effect of the coal in this district.

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*Construction Engineer, Consolidated Ice Co., Pittsburgh.

Mr. W. E. Porter:* Relative to the steam jets you described, what has been your experience in their application to the ordinary setting with vertically baffled B. & W.. type boilers of about 250 to 300 h.p. I mean what are the possibilities of making a smokeless job with such steam jet application as a temporary expedient.

Mr. Monnett: You said the whole thing in the last clause of your question, *temporary expedient.* I would not consider that the combination would be satisfactory permanently. The hand fired vertically baffled B. & W. type of boiler setting is practically an impossible proposition. It needs a mechanical stoker.

Mr. H. D. Stratton: Has this been tried with air jets instead of steam jets?

Mr. Monnett: Not under my personal observation, but I have heard of such experiments. Here is the proposition with steam: You run the steam jets four minutes after each firing. Place the amount of steam used by the steam jets at 10 percent of the total steam generated, for four times an hour. you only run about 16 minutes, so you are only using, at the outside, 2½ percent of the steam generated. I figure that, with the standard steam jet as shown, we are only using at the most liberal figures 2 percent of the steam generated to keep down smoke. With a cheap setting, costing not more than $75 or $100, why isn't it a pretty good proposition? You can put in a stoker to do the same thing, which will cost a thousand dollars, and it will pay a good interest on the investment; but there are so many hundreds of little fellows who are struggling along and can never consider stokers. If you have a high stack, you do not need steam jets at all.

Mr. Norman L. Shaw:* Is the capacity of hand fired boilers somewhat reduced by adding baffle walls and, when the setting is low, is there not a tendency to fill up with dust and clinkers where there is not sufficient time to clean it out between periods? Also, does the Chicago Smoke Department check up all the new installations of boilers as to drafts, capacity, and size of stack, etc.? Sometimes furnaces, other than boiler furnaces, smoke, in the metallurgical and other industries, for instance; do you recommend anything to take care of those?

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*Assistant Chief, Bureau of Smoke Regulation, City of Pittsburgh.

*Master Mechanic, Singer-Nimick Works, Crucible Steel Co. of America, Pittsburgh.

MR. MONNETT: If such a setting is allowed to clog up with soot it would decrease the draft and decrease the capacity of the unit. They must be out of service long enough to be kept clean. But if they are properly put in and cleaned it does not cut the capacity of the boiler. With a draft gauge reading to 0.01 you can hardly detect the difference in draft over the fire and in the combustion chamber with a properly designed No. 8 furnace. But if you do not get the proper proportion, you will burn out the brick work and will not have any success at all. Those ratios have to be worked out very carefully to be successful.

We did have a great many special furnaces to contend with. The best solution for annealing ovens is powdered coal. We have some very large installations of annealing ovens running on powdered coal and saving money. The powdered coal people guarantee 30 percent saving over hand-fired raw coal operation and they are very successful in stopping smoke. Some so-called pot annealing ovens have been cleaned up by using semi-stokers. Melting, heating and forging furnaces in Chicago have been cleaned up by under-feed stokers. I would say the under-feed stoker on powdered coal would work out the solution for most special furnaces. I say under-feed, because that type is supplied with air by mechanical means, and does not depend on draft. The only draft necessary is that to take off the products of combustion, and in that case you must provide liberal gas passes.

MR. GEORGE H. DANFORTH:* In view of the purposed ordinance here, it might be interesting to know what classes of installations in Chicago are exempt from this smoke ordinance. The proposed ordinance in Pittsburgh exempts certain apartment houses, private residences, etc.

MR. MONNETT: The smoke ordinance in Chicago exempts nothing but private residences where used for one family. But we found that it was necessary to develop some ruling to take care of some situations. We made a ruling that buildings like apartment houses, small warehouses, or anything that used more than 1200 sq. ft. of steam radiation or its equivalent, must take out a permit to comply with the regulations of the department. That means that anything that is heated by steam or hot water over 1200 sq. ft. of steam radiation or 2000 sq. ft. of water radiation had to put in a smokeless equipment.

MR. GEORGE H. DANFORTH: That would mean not more than about a 2 h.p. boiler?

MR. MONNETT: Yes, if you want to classify horse-power that way. In that way we exercise supervision of everything smaller than a six flat building.

MR. T. M. REES:* Mr. Monnett has given the number of square feet of grate and the number of square inches over the bridge wall forward of the combustion chamber, and has shown the combustion chamber; but I did not notice any figures given or shown on the drawing regarding the distance between the rear wall and the boiler. Have you not found it essential in your furnace to have the proper area between the rear wall and the boiler? I have found this to be very essential in furnaces in this section.

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*Structural Engineer, Jones & Laughlin Steel Co., Pittsburgh.

*Vice President, James Rees & Sons Co., Pittsburgh.

Mr. Monnett: It is pretty difficult to cover all these points in an hour, and I thought that unless some of these were brought up specifically I would not go into them so deeply. For information, I will give you the standard worked out for a 72 x 18 ft. boiler: Thirty-six inches is required from the back head to the back wall. We ask for a free opening of 25 percent of the grate surface, through the butterfly arch and 40 percent of the grate surface between the back of the bridge wall and the deflection arch. Also 50 percent of the grate surface in free opening under the deflection arch, which is ordinarily in one span, and the floor of the combustion chamber on a level with the firing floor all the way back and paved with a second grade of fire brick laid on edge. All this brick work must be away from and not touching the boiler. We specify a 2-inch clearance to get away from buckling the plates.

Mr. T. M. Rees: If I had a boiler and furnace to build in Pittsburgh I would make that about 15 in. instead of 36 in., or not exceeding 18 in., to make it economical and have a good draft.

Mr. Monnett: We have had a great many of them set 24 in., but we find that where the gas pass has to make a 180° bend we have an excessive draft loss.

Mr. J. W. Henderson:* These dimensions you mention have all been worked out as the result of tests before and after, getting smokeless operation, were they not?

Mr. Monnett: Yes, we installed this type of setting in probably 200 installations a year for the last seven years.

Mr. B. S. Rederer: I had an experience with two 72 in. x 18 ft. boilers set in a battery, which boilers were to be set 24 in. from the rear head to the inside of the rear wall, the standard Hartford setting. By mistake our customer set one of the boilers 14 in. and only got about 75% of rating with natural draft. They later had it changed to 24 in. and got the full rating on the boiler without trouble. This was not a smokeless proposition.

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*Chief, Bureau of Smoke Regulation, City of Pittsburgh.

MR. MONNETT: That corresponds to my experience that any restriction of the gas passages will cut the rating.

MR. J. W. HENDERSON: In a plant in New Castle making shells, where any oxidation of metal on the surface should show up in the finished product, they are using underfeed stokers and doing it successfully. If you have an excess of carbon you have no oxidation.

AN OUTLINE OF THE THEORY OF HEAT TRANSMISSION AND ABSORPTION IN APPLICATION TO ORDINARY ENGINEERING PROBLEMS

By JOHN E. BELL*

Heat can be transferred between substances in three different ways, by radiation, conduction and convection, and it will be my object in this paper to give briefly some account of the theory applicable in each case, in so far as it is useful in understanding the derivation of formulae. Within the limits assigned by the paper it is, of course, impossible to treat any one phase of the subject thoroughly, but it seems to me that much of the important information can be given in a condensed way without losing value. Before entering into the technical treatment I will, with your permission, give some account of the structure of matter as it is now understood, as it may help to make clear statements made later on and, besides, may be of general interest.

Matter is known to be made up of almost inconceivably small particles called molecules which, in different substances, vary in weight and complexity of formation. When the molecules are separated by distances comparable to their size, there is an inter-action which seems to be an attraction when they are near together and a repulsion at a distance. In a solid the attractive forces bind the molecules, so the only motion possible is one of vibration about a position of equilibrium. In a liquid the attractive forces are less and the molecules can move from one position of equilibrium to another. In a gas the molecules are separated beyond the range of attraction and consequently move in straight lines until two collide, when they are deflected in their line of motion by forces which seem to be repellent. The molecules, or rather the atoms which combined form the molecules, were once supposed to be infinitely small particles of matter obeying the ordinary laws of motion. It is now thought, however, that they are of a nebulous structure. At the center is a core or nucleus, and moving around it are numbers of small so-called electrons or corpuscles. These electrons carry a charge of negative electricity and the nucleus contains a balancing charge of positive electricity. The electrons are of one sort in all kinds of atoms. They have been isolated and their mass determined. It is 1/1700 that of an hydrogen atom, and is apparently not mechanical mass at all, as ordinarily understood, but is the inertia effect due to the electro-magnetic field produced by the charge. Part of the electrons are free to move under the attractions of neighboring molecules and pass from one to the other, or else move freely in space. Particularly is this true in good electrical conductors. It also appears that, to a certain extent, in all bodies the molecules dissociate so that any substance is, as a matter of fact, made up of molecules, atoms and electrons. In a solid, as pointed out above, the molecules, while free to vibrate, are held in fixed positions. The electrons, however, move about among the molecules much as the molecules themselves move in a gas, and they carry energy from one position to another.

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The velocity of a moving molecule or electron due to collisions and attractions of neighboring molecules is continually changing. Some will have very little motion, while others will either vibrate or move at a high velocity. There must, however, be some definite distribution of velocities amongst the myriad of particles constituting an appreciable weight of matter, which always keeps a fixed number with velocities between set limits. This distribution of velocity, it is found, makes the mean kinetic energy of the electrons the same as the mean kinetic energy of the molecules. This mean kinetic energy of motion of the particles is the same for all substances at the same temperature. It has been known for a long time that this was true of gases, but only in recent years has it been demonstrated to be true for all substances and also for electrons.

When there is a difference in temperature, the molecules and electrons moving in the direction of the lower temperature have a higher velocity and carry more energy than those moving in the other direction. There will, therefore, be a transfer of energy in the form of heat and the process described is that of conduction. In metals the heat carriers are largely the electrons and, for this reason, good electrical conductors are also good heat conductors. In a gas the carriers are the molecules. As the electrons have the some kinetic energy as the molecules at the same temperature, but move with very much higher velocities, it is obvious that conduction in this way will be at a more rapid rate in solids than in gases. The molecules are also closer together and collide more frequently.

When two molecules collide the shock sets the electrons vibrating, and the vibrations start trains of electro-magnetic waves. The energy transferred in this way is said to be transferred by radiation. When the molecules are near the surface of a solid this radiant energy passes out of the solid entirely; in the interior it is absorbed by other molecules and, when there is a difference in temperature, assists in conduction of heat. Radiation from solids is made up of waves of varying lengths, and the proportion of energy carried by waves of a given length varies with the temperature and the physical properties of the solid. If the radiation is from different sources of varying temperatures, the distribution of energy between different wave lengths might be most anything desired. It is true that the stream would carry a certain amount of energy, but this energy could not be associated with any fixed temperature.

The radiation through an opening in an enclosure at a uniform temperature is independent of the substances forming the walls of the enclosure. Radiation from a source of this sort is said to be full radiation. At high temperatures all solids seem to emit full radiation, but this is not even approximately true at lower temperatures. It is for this reason that radiation pyrometers, which measure only the total amount of energy received, to read accurately should be exposed to full radiations from surfaces all at the same temperature. If the radiation is from surfaces of different temperatures, the reading shows that the sum total of the energy received is the same as that from a source giving full or black body radiations at the temperature indicated.

A body emitting full radiation loses energy at a rate proportional jointly to the bounding surface and to the fourth power of the absolute temperature. If the surface is such that one part can radiate heat to another part, this statement is not accurately true. For the total energy emitted to be proportional to the surface the rays must travel clear from every point. This law is known as Stefan's law and was originally stated as an empirical expression of experimental results that were later on shown to be in error. Its accuracy, however, has since been established experimentally, and Boltzmann has deduced it entirely from the theory of electro-magnetic radiation so that it is now considered a statement of fact. Expressed in B.t.u.'s per hour per square foot of surface, the radiation from a body at the temperature T in degrees Fahrenheit (absolute) is very nearly

$$1600\left(\frac{T}{1000}\right)^4$$

Very hot bodies, regardless of their physical characteristics, seem to emit heat at the rate just mentioned. At lower temperatures the physical characteristics of the surface influence the wave lengths of the vibrations, and the radiation is no longer of the character assumed in the statement of Stefan's law. Inaccuracies in deduction from its practical application are not due to this, however, as much as to inequality of temperatures. In most cases, in addition to the hot surfaces, cooler surfaces are present and absorb radiant heat. These surfaces in turn radiate at a rate dependent on their temperature, and the net effect is measured as the difference between the amount emitted by the hot bodies, according to the law above, and that returned by the cooler surfaces. If the exchange of radiation is between two plane surfaces, one at the temperature T and the other at the temperature t, the net effect is a transfer of heat per square foot of surface of

$$1600\left[\left(\frac{T}{1000}\right)^4-\left(\frac{t}{1000}\right)^4\right]$$

If the higher temperature is 3000° (2540° F.) and the lower temperature is 1000° (640° F.), the heat transferred, according to this formula, is 98 000 B.t.u.'s per hour per square foot of surface, which is heat enough to evaporate 100 lbs. of water per hour. If the temperature of the cooler surface is reduced to

500° (40° F.), the heat transferred would be almost the same, so that when there is as much difference in the temperatures as that assumed, the actual temperature of the cooler surface is of little consequence. In very few cases is the exchange between surfaces as simple as between two parallel planes emitting and absorbing full radiations. In a boiler, for instance, the tubes exposed to the furnace heat receive radiation from the very hot fire bed and from surfaces of the brick wall that vary in temperature from something near to that of the fire bed to a temperature not much different from that of the tube. Under these circumstances, it is not possible to make any accurate calculation as to how much heat can be exchanged by radiation, even though it is assumed that Stefan's law applies. Nevertheless, if it is conceived that the radiation is from a glowing surface, at the temperature a pyrometer would show in the furnace, the radiant heat absorbed is, I believe, not much different from that given by Stefan's law. I have had a number of opportunities of checking this roughly. In one case a lower tube was removed from a B. & W. boiler fired by a Taylor stoker. The tube was replaced with another shorter one of the same size, which extended through the header at one end and just entered the first baffle at the other. Both ends were closed and connections made for circulating water through it. The water was weighed and the rise in temperature taken. The heat absorbed corresponded to an evaporation of 75 lbs. per sq. ft. of surface per hour, more than ten times the average for the boiler. The surface on the top of the tube did not receive radiation, and the bottom surface not only received radiation, but also the heat due to the impingement of the furnace gases, which, I imagine, is at a very high rate. If two-thirds of the surface is considered to be effective, the evaporation would correspond to 112 lbs. per sq. ft. Of this, more than likely, 100 lbs. was from the radiation and 12 lbs. from the heat of the first impingement of the gases. A pyrometer in the furnace would have recorded about 2500° F., so that the evaporation observed checked with the formula with as much accuracy as can be expected. More recently the Power Specialty Company experimented with a new design of superheater placed in the roof of a furnace, directly over the grate surface, which received its heat entirely by radiation. The heat absorbed was found to be little different from that predicted by the formula.

The amount of heat transferred by radiation falls very rapidly with the temperature. A drop in temperature from 2500° F. to 2400° F. will reduce the amount so transferred by 12 percent. It rises with temperature still more rapidly. It is for this reason that boilers with hot furnaces can so easily be overloaded.

If, to refer to the formula again, the higher temperature is 120° F. and the lower temperature 60° F., the heat transferred is 64 B.t.u.'s, or at a rate of 1.07 B.t.u.'s per hour per square foot of surface per degree Fahrenheit difference in temperature. Experiments with radiation in a vacuum at these temperatures give higher results. McFarlane's experiments, referred to in Preston's "Theory of Heat," give 1.7 B.t.u.'s for polished surfaces and 2.4 B.t.u.'s for blackened surfaces. It is probably not far out of the way to assume that heat is lost by radiation from bodies at ordinary temperatures at a rate of 2 B.t.u.'s per square foot of surface per hour per degree Fahrenheit difference in temperature.

If a pyrometer with a protecting casing is used to measure temperatures, the effect of this radiation should be considered. If, for instance, the pyrometer is put in between the tubes of a boiler, it will read low. How much the reading will be off will depend on the rate of absorption of heat by contact with the gases, as compared with the radiation loss. With a smoky gas an interchange of radiations is with particles at about the gas temperature, so there should be no correction to make. With a clean gas, however, the radiation is to the boiler surface. If the letter n is used to represent the ratio between the rate of transfer due to radiation and rate of transfer due to exposure of the gas flow, the pyrometer rating must be increased by n times the difference between the pyrometer reading and the temperature of the boiler tubes. The value of n will depend on the velocity of the gases; usually it will be probably about 0.25. Where the difference in temperature is 100° the correction will be 25°. If, however, the difference in temperature is as much as 1000°, the correction would be around 250°.

If, when considering radiation between two plane surfaces, an intermediate surface is included, this must receive as much heat from the hot side as it radiates from the cold side, and in each case the amount of heat is equal to that transmitted from the hotter surface to the colder surface. If the equations according to Stefan's law are written down for both sides of this plate and added together, the temperature of the plate is eliminated and the result is that the total transfer is in accordance with Stefan's law, with a constant of just one-half the amount. If two intermediate surfaces are in position, the radiation constant is reduced to one-third, and so on. It is evident that such an arrangement would constitute an effective screen against the losses of heat by the hotter body. A pyrometer inside of a cylinder with the gas flowing freely on both sides will not be affected in its reading by the temperature of the surrounding bodies anything like as much as it would without the screen. A plate set along the side walls of a boiler a few inches away from the surface will not be as hot as the surface, and if the air for combustion is drawn down between the furnace wall and this plate the insulation against a loss of heat is probably as effective as can be obtained. In a gas the interchange of radiation between molecules is somewhat in this same way, so that its effect on the conductivity is limited.

It was pointed out in the foregoing that heat was conducted through gases by the vibrating molecules and through metals, to a large extent, by vibrating electrons. In other solids which are non-conductors of electricity and in liquids the heat is probably transmitted largely by contiguous molecules clashing against each other in their vibration, and possibly by inter-molecular radiation. The electrons, on account of their high velocity, should be the most effective as carriers, and it is therefore to be expected that the metals show the highest conductivity. Other solids and liquids should have values much lower, and this experimental data shows to be the case.

It is convenient to refer to conductivity of substances as measured by the number of B.t.u.'s transferred per hour through a slab of the material one foot square and one inch thick when the difference in the temperature of the two faces is 1° F. This unit is 2904 times the C.G.S. unit used in scientific tables. The values of this co-efficient for a number of substances I give below, with a note of the authority:

Aluminum	1394	at 64° F.	(Smithsonian Physical Tables)
Copper	2666	at 64° F.	(Smithsonian Physical Tables)
Cast Iron	314	at 64° F.	(Smithsonian Physical Tables)
Wrought Iron	418	at 64° F.	(Smithsonian Physical Tables)
Soft Steel	322		(Smithsonian Physical Tables)
Hard Steel	180		(Smithsonian Physical Tables)
Water	4.16	at 68° F.	(Encyclopaedia Britannica)
Fire Brick	4.5		(A mean value only)
Air	0.165	at 60° F.	(Dynamical Theory of Gases—Jeans)
Hydrogen	1.6	at 60° F.	(Dynamical, Theory of Gases—Jeans)

The conductivity of perfect vacuum would be zero. Heat is only transmitted through a vacuum by radiation.

The conductivity of all substances vary with the temperature in a manner that is not entirely understood. The electronic theory of conduction in metals makes the ratio between the heat conductivity and the electrical conductivity proportional to the absolute temperature, and in good conductors this seems to be the case. The thermal conductivity on this same basis would be constant, but as the theory has not, as yet, been satisfactorily worked out in all details, this undoubtedly is incorrect. There is hardly enough data for liquids to say whether the value increases or diminishes with a rise in temperature. In gases the heat carriers, the molecules, also carry momentum from one layer of gas to another when subject to a shearing motion and, according to the kinetic theory of gases the co-efficient of conduction is directly proportional to the specific heat at constant volume times the co-efficient of viscosity. This relation seems to hold very well for the permanent gases. If it does hold, the co-efficient of conductivity for air has a temperature factor:

$$\frac{C_v\, T^{\frac{3}{2}}}{T + 185}$$

where T is the absolute temperature in Fahrenheit degrees.

The high value of the co-efficient for hydrogen is due, of course, to the high specific heat of this gas.

The change of the co-efficient with pressure in a gas is probably negligible for all ordinary pressures, as it is known that the co-efficient of viscosity is independent of the pressure.

It is almost impossible to measure the conductivity of either liquids or gases accurately on account of the convective currents due to differences in density. It is, for this reason, that little is actually known about the variation with temperature. It would seem, however, that the actual value of these co-efficients is relatively unimportant in the theory of heat transfer as, in this particular, the predominating influence is the internal motion of the fluid.

The motion of fluids has always been a subject of interest to physicists and mathematicians and has received a great deal of attention. In spite of this, the electronic theory which has been developed in the last fifteen years lends itself better to the interpretation of experimental data than any general theory of fluid motion so far propounded. This is entirely due to the impossibility of solving the general equation for the motion of a fluid subject to internal friction due to what is known as viscosity. The only motion subject to treàtment is that used in determining the co-efficient of viscosity of the fluid, namely, a straight stream line motion through a channel, or a motion in circular stream lines between rotating cylinders. In both of these cases the velocity of a fluid particle does not change during its motion. When the velocity does change, as is true in actual cases, the mathematician is entirely helpless. The most complete treatment of this subject in any language is Lamb's "Hydrodynamics." There is a new edition out this year. Lamb does not give a solution of even the simplest problem of the motion of a viscous fluid when the velocity varies throughout a stream line.

In a so-called perfect fluid it is assumed that there is no resistance to a shearing motion, and the theory on this basis is quite complete. It is sufficient to account for the wave motion in bodies of water and for sound waves in gases. Also, to a lesser degree, the formulae for jet motion in two dimensions for flat plates seem to check up with the experimental data, but this is not true for cylinders or spheres moving through a fluid. Even assuming the absence of friction, there is no accurate formula applicable to the motion of a gas where there are variations in pressure and density. I have elaborated a little on this point as, unless one is familiar with the subject, he is apt to be misled by much that has been published in connection with heat transfer formulae into believing that it is possible to calculate results from a fundamental basis.

The theory of the motion of a perfect fluid contained between surfaces requires that the fluid move without friction and with assignable velocities over the surfaces. Since fluids are known to be of a granular construction and solids are also known to be of the same nature, it is a physical impossibility for any fluid to have a velocity next to a surface other than the velocity of the surface itself. In gases at very low pressure the fluid characteristics are lost, and it has been customary to refer to a slip at the walls, but this does not in any way affect the statement just made. There are many reasons, however, for believing that at some distance from a boundary a fluid will move as a perfect fluid, as in observed motion the energy lost by friction is small in comparison with the total energy. Again, smoke rings and other forms of vortex motion follow very accurately the predictions from the theory. In circular pipes, however, and other forms of channels this is not the case at low velocity. Professor Osborn Reynolds has popularized this knowledge by experiments with glass tubes, through which water flows, with a small colored stream at the center. At low velocities this was drawn out to a fine ribbon. As the velocity increased a point was reached where the colored stream would wave from side to side and would then break up and the color would be diffused from wall to wall, indicating the presence of cross currents comparable in magnitude to the mean velocity through the tube.

In all formulae that are accurate and not empirical every term must be measurable in the same units, whatever this unit may be. When the number of quantities that can enter into the result is limited to three, four or five, a great deal of knowledge has been derived from this one consideration. Professor Reynolds assumed that motion in a pipe was influenced only by the mean velocity of flow, the viscosity, density and diameter of the pipe. On this basis he concluded that the critical velocity in all fluids would be proportional to the co-efficient of viscosity divided by the product of the density and diameter, and experi ments in a way check this out. If, however, vibrations such as sound waves have an influence on breaking down the motion, this conclusion would not be correct, and recent investigators seem to believe that something of this sort actually occurs. When the pressure drop is included there are five quantities involved in the motion. These can only be combined in two ways to give terms of zero dimension, and if it is assumed that these five measurable quantities are the only ones to be considered, one of these terms must be a function of the other. Stanton and Pannel, following out a suggestion of Lord Rayleigh, have shown that this is true, and from their experiments formulae for friction loss of pressure have been developed that are applicable to any fluid, provided the motion is one that does not change the density. In this formula the co-efficient of viscosity produces a negligible result at high velocities. The constant in the ordinary pressure drop formula at high velocity holds for all fluids. It is for this reason that I made the statement above that the co-efficient of conductivity, which is directly related to the co-efficient of viscosity, has probably little bearing on heat transfer in pipes or channels. Heat is carried across the pipes to the walls by cross currents.

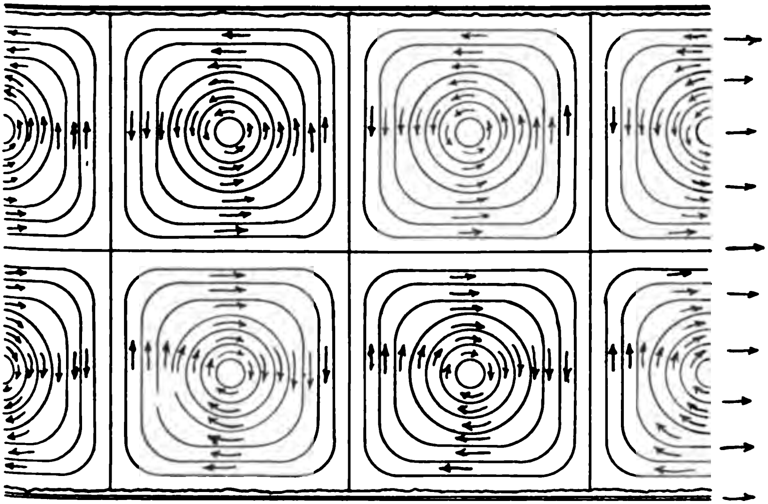


Fig. 1. Stream Lines of a Fluid in a Pipe Relative to an Observer Moving With the Mean Velocity of the Fluid.

If in a pipe the fluid is supposed to carry a series of diaphragms or pistons that move with the mean velocity of the flow, it is obvious that there will be a rolling motion from side to side, something of the character I have sketched out in Fig. 1. In effect the motion is much the same as if there were a closely packed procession of vortex rings just like the ordinary smoke rings. The mean velocity in this motion has a very specific meaning, and the observed velocities across the section of the pipe would vary much, as they actually do. Along the walls there must be a thin layer, in which the velocity increases very rapidly from zero at the walls to something like 70 percent of the mean velocity a very short distance away. These two forms of motion, it would not seem, could come together along any surface that would be a surface of equilibrium, and I am inclined to think that it is being continually broken up and eddies or small vortex filaments of the hot fluid are being carried into the layer, where the vortex motion is quickly sheared out. This form of motion could be determined from the density and viscosity theoretically without introducing any other of the physical characteristics, and this seems to be necessary from Stanton's and Pannell's experiments. The heat transferred through this film would be divided in two parts, a small amount proportional to the coefficient of conduction and a large amount carried by the fluid actually entering the film. The change in momentum of this would also produce a drop in pressure and, if this is taken as proportional to the square of the velocity and the density jointly, the amount of heat carried would be measured by the continued product of the specific heat, density, mean velocity and temperature difference. The product of the density and mean velocity is the weight or mass flow per square foot of channel area, so that the heat absorbed can be written as

$$H = (a + bw)\ (T - t)$$

Where H is the B.t.u.'s transferred per hour per square foot of tube surface

T = the mean temperature of the fluid.
t = the temperature of the tube wall.
a = a constant probably proportional to the conductivity.

b = a constant that is proportional to the specific heat and also varies with the temperature in some way that so far seems obscure.

w = the mass flow per unit area of the channel.

The quantity multiplied into the temperature difference in the above formula is usually called the transfer rate and will be distinguished by R. It is measured in B.t.u.'s per hour per square foot of surface per degree Fahrenheit difference in temperature. It varies in value with gases from 2 to 10 or 12, and with water from 400 to 3000, depending on the mass flow.

In this form the transfer formula was first proposed by Professor Osborn Reynolds. He deduced it partially by considering the motion of a viscous fluid, but largely from the theory of dimensions. The fluid motion that he conceived as existing in a tube was of the so-called turbulent type, which is entirely different from that suggested above. The results deduced in this paper depend entirely on the motion through the surface film, which is assumed to be of the definite character outlined. The usual notion that the thickness of this wall film varies with the mean velocity of flow and that particles of fluid are torn away from the rest, due to the roughness of the surface, does not bear accurate scrutiny. There is no such a thing possible as a tearing motion in a fluid, and if the thickness of the film controls the heat flow the transfer equation would not be in the form deduced by experiment.

The ordinary formulae used in connection with the transfer of heat between a fluid in a channel and the walls are not complicated and have probably been known since the calculus was invented. They are determined from equating the heat absorbed by the tube walls, using the transfer equation given above, to the heat lost by the fluid. As stated, this assumes the fluid to be hotter than the tube walls. When, however, the tube walls are hotter than the fluid the same equations apply with slight changes.

The formula most commonly used assumes a transfer rate which applies to the difference between the mean gas temperature and the mean tube temperature, and is usually written as follows:

Representing the temperatures by

T_1 at the hot end.
T_2 at the cold end.
t_1 is the wall temperature at the hot end.
t_2 is the wall temperature at the cold end.

The mean gas temperature is

$$\frac{1}{2}(T_1 + T_2)$$

and the mean tube temperature is

$$\frac{1}{2}(t_1 + t_2)$$

The surface between is S, and the heat given out is equal to

$$H = SR\left(\frac{T_1 + T_2}{2} - \frac{t_1 + t_2}{2}\right)$$

It is also equal to

$$H = Wc(T_1 - T_2)$$

where W is the weight flow in pounds per hour and c is the specific heat. When these two values are equated the first general equation used in heat transfer is obtained

$$S = 2\frac{Wc}{R}\frac{(T_1 - T_2)}{(T_1 - t_1) + (T_2 - t_2)} \qquad \text{(1)}$$

If an equation of more accuracy is required, this can be written in its differential form and integrated. In its differential form it becomes

$$R(T - t) = -Wc\frac{dT}{ds} \qquad \text{(2)}$$

This equation is really the foundation of the whole theory of heat transfer. It determines the transfer rate and also the mean temperature, as these two are interconnected. If in the flow as outlined the temperature of the wall film on the inside is approximately equal to the mean temperature of the fluid, then the temperature gradient is small, and as heat would be transferred along the tube by the internal motion, as well as across the tube, there would be a very considerable flow of heat which would be independent of the actual mean temperature and would make the transfer rates differ between heating and cooling flows. The equation considered assumed that this mean temperature is the temperature of the gas if it could be abstracted at any section and thoroughly mixed, and if there is a flow of heat along the tube due to the internal motion as just outlined this mean temperature would be different from the actual mean temperature in the tube. I will not enter further into this matter, as it is complicated, but I wish to point out that in my mind there is a very serious question whether actual mean temperatures have ever as yet been determined, and consequently the value of the transfer rate will show more or less anomalous variations on this account.

The transfer rate varies some with the temperature. The variation, however, is not marked in most cases. Even where it does vary, if the rate corresponding to the mean temperature is used there is practically no error in considering R as a constant. With this understanding the transfer equation can be integrated, and four forms are given below:

Equation (3) is used when a fluid is being cooled by a surface of constant temperature, as in a boiler.

Equation (4), when a fluid is being heated up by a surface of constant temperature which, it will be pointed out later, approximately holds in a condenser.

Equation (5), when one fluid is being heated and another cooled by a counter-flow.

The equations are all written in the form for calculating the surface required for a given heating or cooling effect.

$$S = \frac{Wc}{R} \log_e \left(\frac{T_1 - t}{T_2 - t}\right) \quad \ldots\ldots\ldots\ldots (3)$$

$$S = \frac{Wc}{R} \log_e \left(\frac{t - T_2}{t - T_1}\right) \quad \ldots\ldots\ldots\ldots (4)$$

t = Temperature of saturated steam at the pressure in the condenser.

W = Weight of water per hour.

$$S = \frac{Wc}{R} \left(\frac{T_1 - T_2}{(T_1 - t_1) - (T_2 - t_2)}\right) \log_e \left(\frac{T_1 - t_1}{T_2 - t_2}\right) \quad \ldots\ldots (5)$$

W = The weight of gas. .
w = The weight of water.
c = 0.25 for furnace gases nearly enough.

$$Wc\ (T_1 - T_2) = w\ (t_1 - t_2)$$

provided there is no air infiltration.

Many kinds of formulae of this sort can be obtained by assuming the transfer rate to vary with the temperature in some empirical way, but I do not believe it is ever necessary to use anything other than the equations given, and in most cases the simple Equation (1) is all that is required.

To use these formulae it is necessary to know the transfer rate, and any experimental research should be solely for the purpose of determining this value of R as it varies with different fluids and with temperature. Unfortunately, some experiments have been made from the viewpoint of establishing some general law, and as a result the data obtained is of not much use until it has been recalculated. Even then there is always a question as to whether the temperatures are properly measured, the effect of conduction along the tube eliminated, etc. There are very few accurate determinations. Mostly the variation between experiments supposed to be duplicates of each other are as much as 10 percent. This is not of much consequence in the practical application of the formula, but it does interfere with any scientific consideration of its variation.

For the purpose of giving values to the transfer rate I wish to refer to three sets of experiments, one set giving the rate for furnace gases in a circular flue made under my direction at Bayonne, the report of which was published in bulletin form by the Babcock & Wilcox Company; second, experiments by T. E. Stanton, published in the Philosophical Transactions of the Royal Society of 1897, giving the transfer rate for water in a tube; and third, to the experiments of Mr. George A. Orrok with the condensation of steam, published in the Transactions of the American Society of Mechanical Engineers, 1910. I have selected these experiments, as they are, so far as I know, the only ones which cover a sufficient range to be of much value in general consideration of this sort.

The Bayonne experiments were made with a tube two inches in internal diameter. The mean temperature of the gas was calculated from the heat given out, which eliminates the very extensive errors resulting from an attempt to measure this temperature with a pyrometer. If there is any error in the values assigned to the mean gas temperature, it must come from the flow of heat through the tube produced by the internal gas motion that was referred to above. The transfer rates are determined for the full range of temperatures met with in a boiler, and thus constitute the first set of experiments over this range. A full account of the results and description of the apparatus is given in the report. The results can be summarized as follows:

$$R = 2.1+0.000\,626\,[1+0.000\,575\,(T-t)-0.000\,000\,866\,(T-t)^2]w \quad \dots\dots(6)$$

in this equation w is the weight of gas in pounds per square foot of tube sectional area per hour.

It is to be noted that the transfer rate can be expressed by an equation of the exact form that the theory suggests, even though the theory is somewhat questionable. The increase of the constant a with the temperature difference is negligible, but the variation of the constant b is quite marked. The expression given is entirely empirical, and I am quite sure is not as it would be if the exact form were known. Below are two other empirical forms in which the temperatures are in degrees Fahrenheit (absolute):

$$R = 2.1 + \frac{w}{1650}\,\frac{T}{T-t}\,\mathrm{Log}_e\left(\frac{T}{t}\right)$$

$$R = 2.1 + 0.00193\left(\frac{T+360}{T+2500}\right)w$$

In the first of these expressions the constant b is of the form suggested for the complete transfer rate co-efficient by Professor Fessenden in a paper read before the American Society of Mechanical Engineers last Spring. This is a one-constant equation, and ordinarily would be considered as of more importance than any other form of expression. I believe, however, that it is simply coincidence, as I cannot conceive of the effect of the variation with temperature, density, conductivity and viscosity being grouped together and controlled by one constant. Since further there is no theoretical reason for assuming this form, and as it is impossible to integrate the general equation with its use, I give it here, together with the other, simply to emphasize how easy it is to get formulae for temperature variations and for heat absorption that differ from the simpler equation given, only in the assumption made as to the form of the expression for the heat transfer rate.

The Bayonne experiments do not show the variation with tube temperature. It was originally intended to obtain this data, but the tube temperature had to be kept around 180° F. to prevent trouble from moisture in the gases, and this did not leave enough range with the way the apparatus was designed to make it worth while attempting a second set with different tube temperature. For the investigation to be complete this should be determined. For all ordinary purposes, however, I am inclined to believe the first value for the transfer rate can be used even with different tube temperatures without serious error. It probably also can be used with tubes of different diameter.

When the gas flow is over tubes at right angles to their length, as with horizontal boilers cross baffled, the mean transfer rate is very nearly

$$R = 2.0 + 0.0014w \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

In this expression w is equal to the total weight of gas divided by the net area between the tubes in one row as averaged between the different passes. The value of b is more than the value of the constant in the expression applicable to a circular flue, and is due probably to the effect of staggering the tubes, but it is to be remarked that for the same velocity the friction loss would be more, so that for the same friction loss the value may not be much different.

At very high velocities the transfer rate is almost directly proportional to the gas flow. When this is true and the corresponding value of R is substituted in Equation (3) the gas weight cancels out, and under these conditions a given area of surface would cool a hot gas the same amount, regardless of the amount of gas that is swept over the surface. At lower velocities the first term in the expression for the transfer rate is relatively of more importance. In boiler work around rating the gas flow is usually about 1000 lbs. per sq. ft. of net area per hour. The corresponding transfer rate is 3.4, of which amount 2.0 is from the constant term and 1.4 from the term that varies with the gas flow. It is, therefore, to be expected that flue gas temperatures should increase as the capacity increases in all cases, and this is, of course, true. The second term of this heat transfer equation is the one which varies with temperature, so that, when it is small, the variation with temperature is relatively small, and Equation (3) can be used in plotting temperatures through a tube in a flue boiler or between the tubes in a water tube boiler. This temperature curve is only of academic interest. Equation (3), together with the equation for the heat transfer rate and the equation for the heat transmitted by radiation from the furnace, gives all the formulae necessary for design work in either type of boiler. There is no such a thing as a theoretical length of tube or of gas travel for the best results. The greater the heating surface and the longer the gas travel, the lower the flue gas temperatures will be and the higher the efficiency. Against this must be balanced the increased first cost and the greater draft required, and the arrangement finally selected must be made from a commercial and operating viewpoint.

If the value of the transfer rate is much affected by the tube temperature the transfer in economizers should be somewhat lower than it is in boilers, and ordinarily transfer rates of only one-half to two-thirds of the amount are used. I believe, however, that the same transfer rate could be used without much error when the tubes of the economizers are staggered and air leakage is entirely excluded. I have had an opportunity recently of testing a Green economizer of this sort, and the heat absorbed was very nearly as much as is absorbed by boiler surface with the same gas flow. In economizer work the approximate formula given in Equation (1) can usually be used without much error. If the flow is counter current, truly speaking, the exact formula to use would be Equation (5). The flow, however, is never just like this.

If, in place of the transfer rate R its reciprocal is used, an expression is obtained which measures the resistance to heat

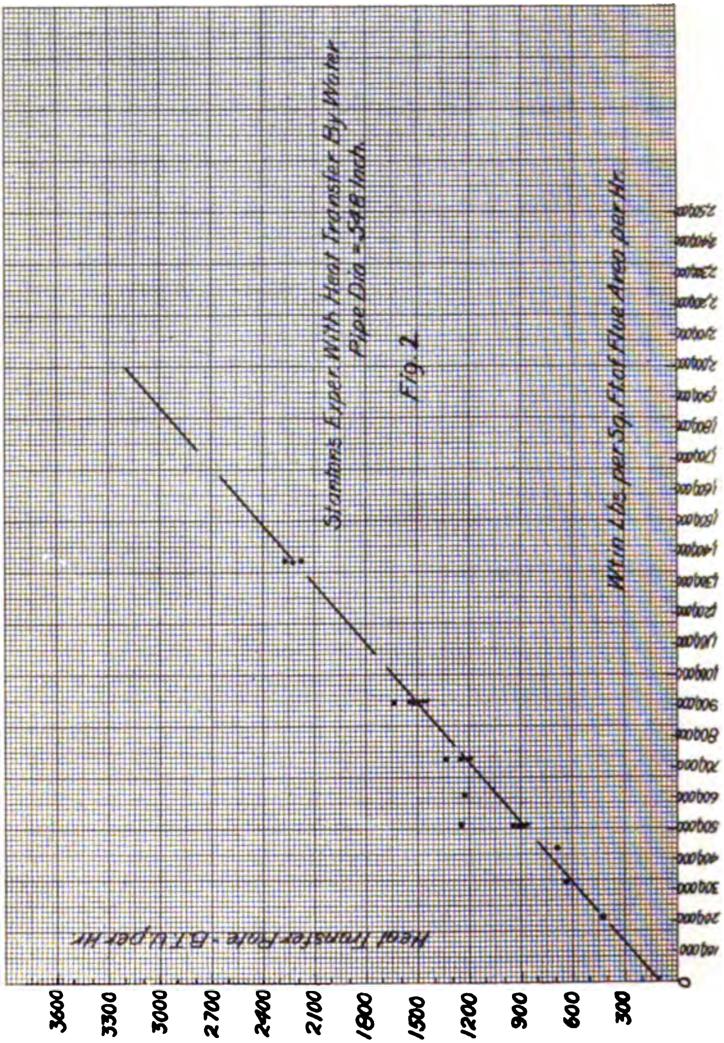

Stantons Exper. With Heat Transfer By Water
Pipe Dia = .548 Inch
Fig. 2
Heat Transfer Rate - B.T.U. per Hr.
Wt. in Lbs. per Sq. Ft. of Flue Area per Hr.
3600
3300
3000
2700
2400
2100
1800
1500
1200
900
600
300
0
100,000
200,000
300,000
400,000
500,000
600,000
700,000
800,000
900,000
1,000,000
1,100,000
1,200,000
1,300,000
1,400,000
1,500,000
1,600,000
1,700,000
1,800,000
1,900,000
2,000,000
2,100,000
2,200,000
2,300,000
2,400,000
2,500,000

Fig. 2.

transmission which is directly analogous to the resistance in electrical work, the difference in temperature corresponds with the difference in voltage and the heat flow to the electric current. The total resistance in a boiler or economizer is the sum of three separate and distinct terms:

First. The resistance to the passage of the heat from the gas to the tube surface, which is measured by the reciprocal of the value of R just discussed.

Second. The resistance in the tube itself, which is equal to the thickness of the tube in inches divided by the co-efficient of conductivity as discussed in the first part of this paper.

Third. The resistance from the tube to the water.

The tube resistance is negligible in comparison with the resistance on the gas side, and it will be seen later on that this also is true for the resistance on the water side so that the total resistance is very nearly equal to the resistance on the gas side. This warrants the use of formulae without reference to the velocity of circulation of the water.

The experiments of Stanton on the rate at which water will absorb heat from a tube were made on three sizes of tubes and approximately, at least, the temperature of the tube surface was observed. His experimental results did not always check one with another and there is some question as to just the amount of surface engaged in the transfer. There was also some transfer of heat at the ends due to conduction. The results were worked up to prove a formula suggested by Professor Reynolds from the formula he had given for the friction loss in pipe lines, which is now known to be incorrect, so that Stanton's paper is of little value with the results as given. I have taken his data, however, and calculated heat transfer rates, which show that very accurately they are a linear function of the mass flow, and can be noted in Figs. 2, 3 and 4. There is some variation of temperature, but the temperature range was not wide and this variation is not excessive. A more marked variation is with the size of the tube. Stanton, in his paper, seems to believe that the tube size made little difference, but when the results are refined as they are in calculating transfer rates this is shown not to be true. Disregarding the temperature variation, Stanton's experiments make

$$R = 110 + 0.00208 \left(1 - \frac{0.139}{d}\right) w \quad \dots\dots\dots\dots\dots (8)$$

The constant b is about three times what it would be for air in the same tubes, and this is not widely different from the ratio of the specific heats. The mass flow, with a fluid as dense as water, runs into large numbers and, since the density does not vary, it is more convenient to use v, the velocity in feet per second, in place of w in the value for R, which then becomes

$$R = 110 + 465 \left(1 - \frac{0.139}{d}\right) v \dots\dots\dots\dots\dots\dots\dots (9)$$

If the errors in Stanton's experiments are what I conceive them to be, the values of the transfer rates at low velocities are too high, which would mean that the constant a is too large. If this constant is proportional to the conductivity, on the basis of the Bayonne experiment, it would be about 50, if this value is used, and for higher transfer rates Stanton's experiments are used. The value for water is

$$R = 50 + 467 \left(1 - \frac{0.133}{d}\right) v \dots\dots\dots\dots\dots\dots\dots (10)$$

In Equations 8, 9 and 10, the diameter of the tube in inches is represented by d.

Further experiments are needed to establish accurately the constants in this formula, as well as their variations with temperature, and it is to be hoped some one will take the matter up.

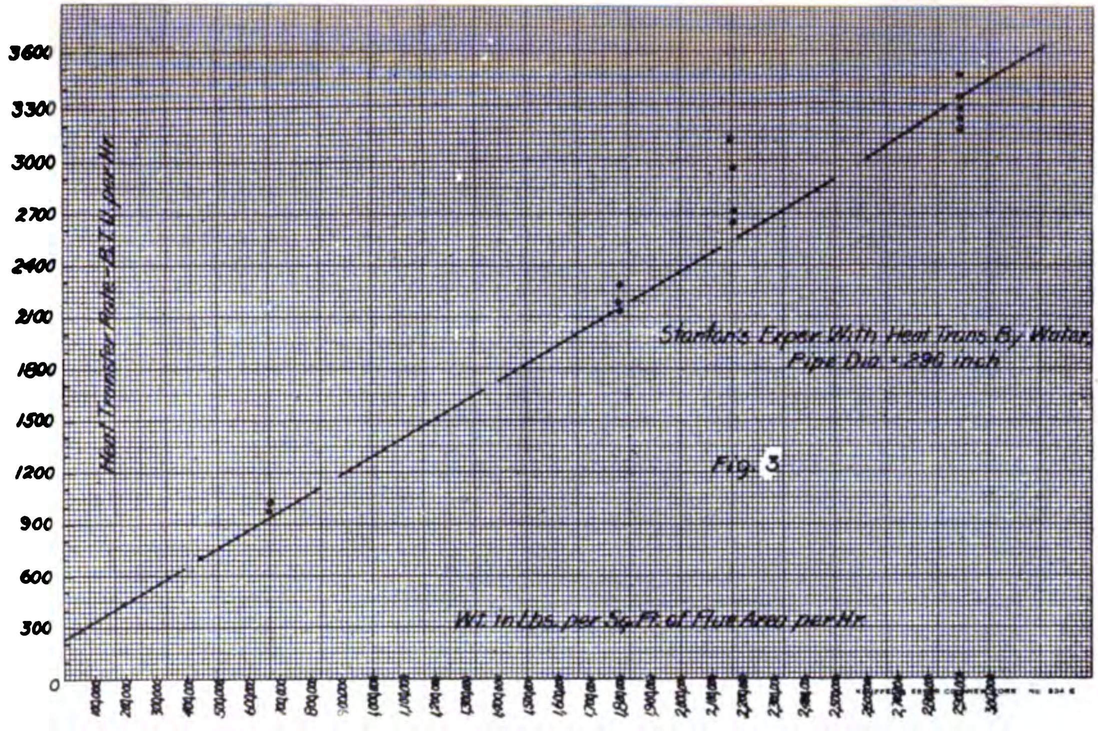
In a condenser the resistance to the passage of heat on the two sides of the tube are of about the same order, so that there is no reason to expect that the transfer rate would increase directly as the water flow or even be any simple function of the flow. The resistance in this case can be divided into four parts:

1. The resistance on the water side, which is the reciprocal of the transfer rate for water given in Equation 10.

2. The resistance through the tube, which is equal to the thickness in inches divided by the value of the co-efficient of conductivity of the metal as used in this paper.

3. The resistance of the film of water which will adhere to the outside of the tube.

4. The resistance to the transmission of heat from saturated steam vapor to the surface of the water of the film, which is probably a constant.


Starton's Exper. With Heat Trans. By Water,
Pipe Dia. = .290 inch
Fig. 3
Heat Transfer Rate – B.T.U. per Hr.
Wt. in Lbs. per Sq. Ft. of Flue Area per Hr.
3600
3300
3000
2700
2400
2100
1800
1500
1200
900
600
300
0
100,000
200,000
300,000
400,000
500,000
600,000
700,000
800,000
900,000
1,000,000
1,100,000
1,200,000
1,300,000
1,400,000
1,500,000
1,600,000
1,700,000
1,800,000
1,900,000
2,000,000
2,100,000
2,200,000
2,300,000
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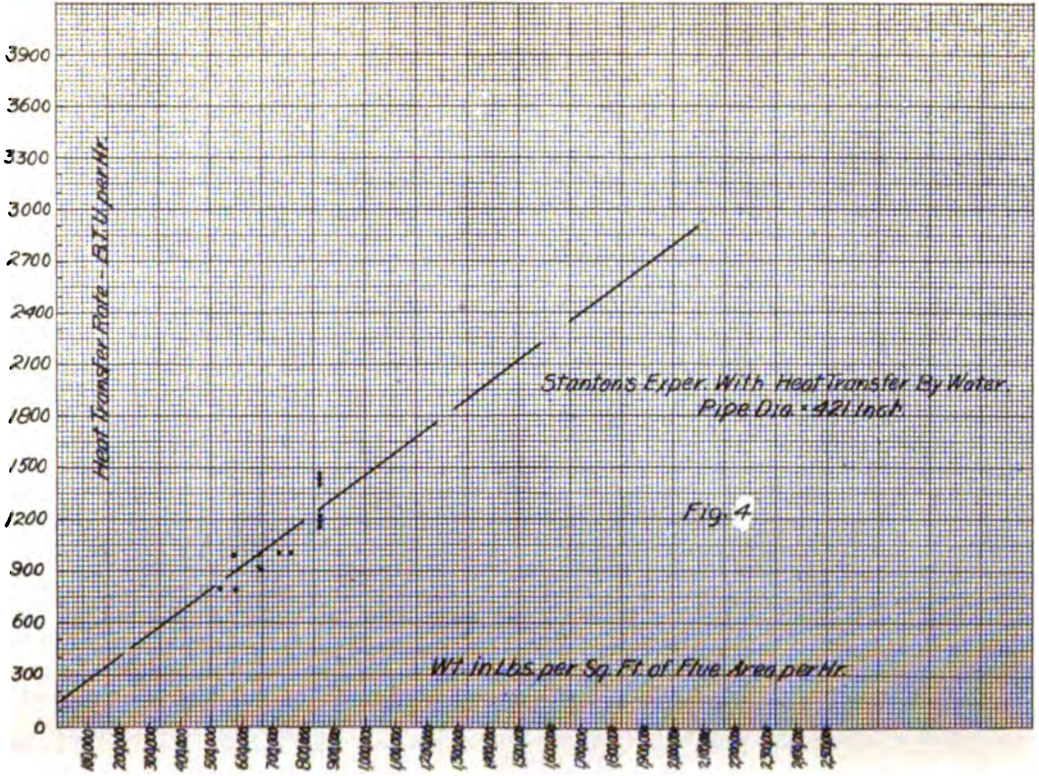
2,500,000
2,600,000
2,700,000
2,800,000
2,900,000
3,000,000

Fig. 3.


Heat Transfer Rate - B.T.U. per Hr.
3900
3600
3300
3000
2700
2400
2100
1800
1500
1200
900
600
300
0
Stantons Exper. With Heat Transfer By Water.
Pipe Dia. = .421 Inch.
Fig. 4
Wt. in Lbs. per Sq. Ft. of Flue Area per Hr.
100,000
200,000
300,000
400,000
500,000
600,000
700,000
800,000
900,000
1,000,000
1,100,000
1,200,000
1,300,000
1,400,000
1,500,000
1,600,000
1,700,000
1,800,000
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2,100,000
2,200,000
2,300,000
2,400,000
2,500,000

Fig. 4.

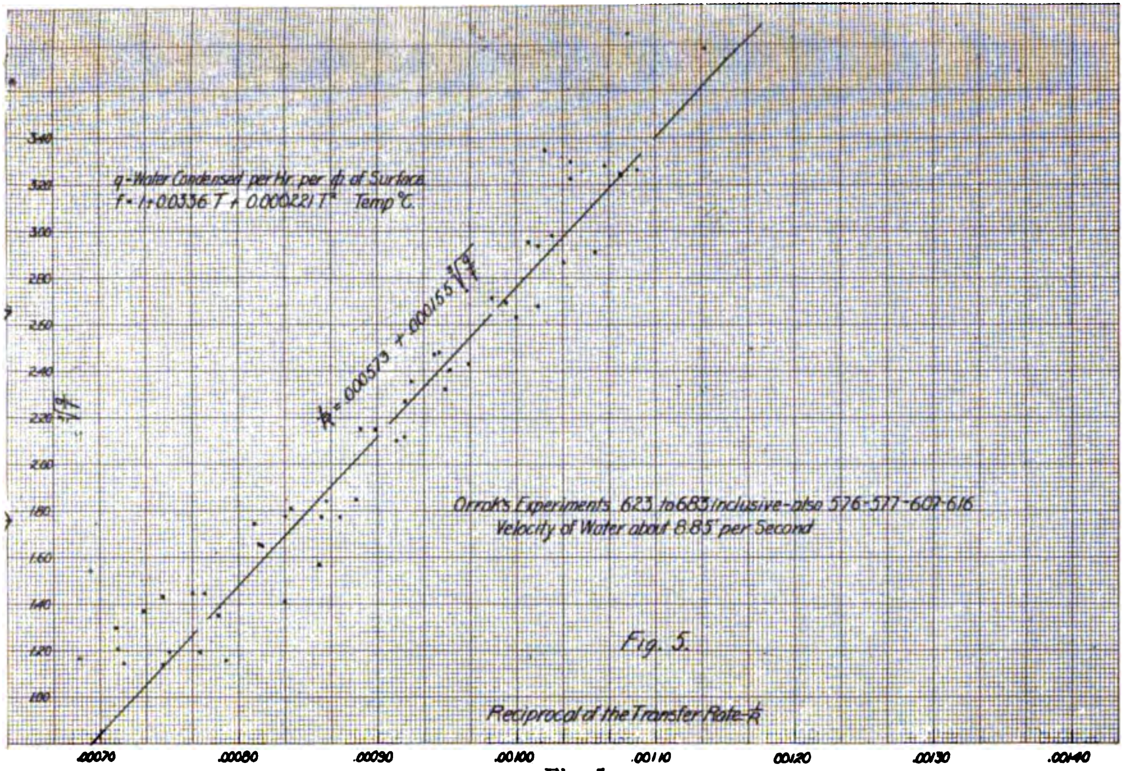
q-Water Condensed per Hr. per ⬜' of Surface
f = 1+0.0336 T + 0.000221 T² Temp °C.
$\frac{1}{k} = .000573 + .000165 \sqrt[3]{\frac{f}{q}}$
$\sqrt[3]{\frac{f}{q}}$
Orrok's Experiments 623 to 683 inclusive-also 576-577-602-616
Velocity of Water about 8.85' per Second
Fig. 5.
Reciprocal of the Transfer Rate-$\frac{1}{k}$
340
320
300
280
260
240
220
200
180
160
140
120
100
.00070
.00080
.00090
.00100
.00110
.00120
.00130
.00140

Fig. 5.

Air when mixed with steam in a condenser exerts a partial pressure, so that the actual temperature of the steam is not that corresponding to the pressure. Before the mixture this would be the case, but afterwards the steam temperature would be lower, as in condensing the heat transfer is almost entirely latent heat, and this heat must certainly be given up at the temperature corresponding to the partial pressure of the steam. Since it is very difficult to measure the difference in these two pressures, and the amount of air present is not known, it is to be expected that accurate experimental data is hard to obtain. This is further complicated by the water film. This water film must increase in thickness with the rate of condensation, as it must be thicker for water to flow more rapidly. The force causing the motion is gravity, and the resistance for such thin films would be entirely that due to viscosity. On this assumption the mean velocity at which the water would flow through the film would be proportional directly to the square of the thickness and to the density and inversely proportional to the viscosity. The total flow which would correspond to the total condensation would therefore be proportional to the cube of the thickness, directly to the density, and inversely to the viscosity. Expressed in another way, the thickness of the film is proportional to the cube root of the product of the water condensed per hour per square foot of surface into the co-efficient of viscosity. The second factor varies markedly with the temperature, and this must be taken into account. The viscosity of the fluid next to the surface is of the most importance, and the temperature used in determining it should be that of the external surface of the tube.

Using letters with the following meaning the transfer rate for condenser tubes can be written down:

r_w = the transfer rate from the water to the tube, which can be taken as equal to the value R given by Stanton's experiments.

r_s = the transfer rate from the steam to the water film, which is taken as constant.

d_1 = the internal diameter of the tube.

d_2 = the external diameter of the tube.

k = the conductivity of the metal of the tube.

t = the tube thickness in inches.
q = the weight of steam condensed per hour per square foot of surface.
f = reciprocal of the temperature factor of the co-efficient of viscosity of water.
j = a numerical constant.

$$\frac{1}{R} = \frac{1}{r_w} + \frac{d_1}{d_2 r_s} + kt + j\sqrt[3]{\frac{q}{f}} \qquad (11)$$

It will be noted that with a constant water velocity the reciprocal of the total transfer rate should be a linear function of the cube root of q divided by f. Mr. Orrok's experiments have been referred to to check this up, and in Figs. 5, 6 and 7 are plotted values taken from the report of his experiments. The value of f used was

$$1 + 0.0336\ T + 0.00022\ T^2 \qquad (12)$$

in which T is expressed in degrees Centigrade.

Only the last series of tests was used, as there seems to be some errors in the earlier tests. It is evident that the law assumed holds closely for the velocities considered; at lower velocities the character of the motion of the water in the tubes changes as an approach is made to the critical value. When it is further considered that any variation in the conductivity of the water with the temperature would throw this out, it appears that the conductivity must be nearly constant. The values obtained from this plot gives j the average value 0.00017.

Taking the conductivity of the tube at 0.0005 and using Equation (10) for the value of r, it further appears that the transfer rate between the steam and the water film is about 3400 B.t.u.'s per degree Fahrenheit difference in temperature. Professor Callender, in the Encyclopaedia Britannica, expresses a belief that steam condenses at a constant rate per degree difference in temperature, and he refers to a paper by himself and Nicholson in the Proceedings of the Institution of Civil Engineers in 1898 for the value.* This paper assigned a value in B.t.u.'s per hour of 2664 and, since it was not determined by direct measurement,

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*Proceedings, Institution of Civil Engineers (British), "On the Law of Condensation of Steam Deduced from Measurements of Temperature—Cycles of the Walls and Steam in the Cylinder of a Steam Engine," Vol. CXXXI, pp. 147, 206, 234, 260.

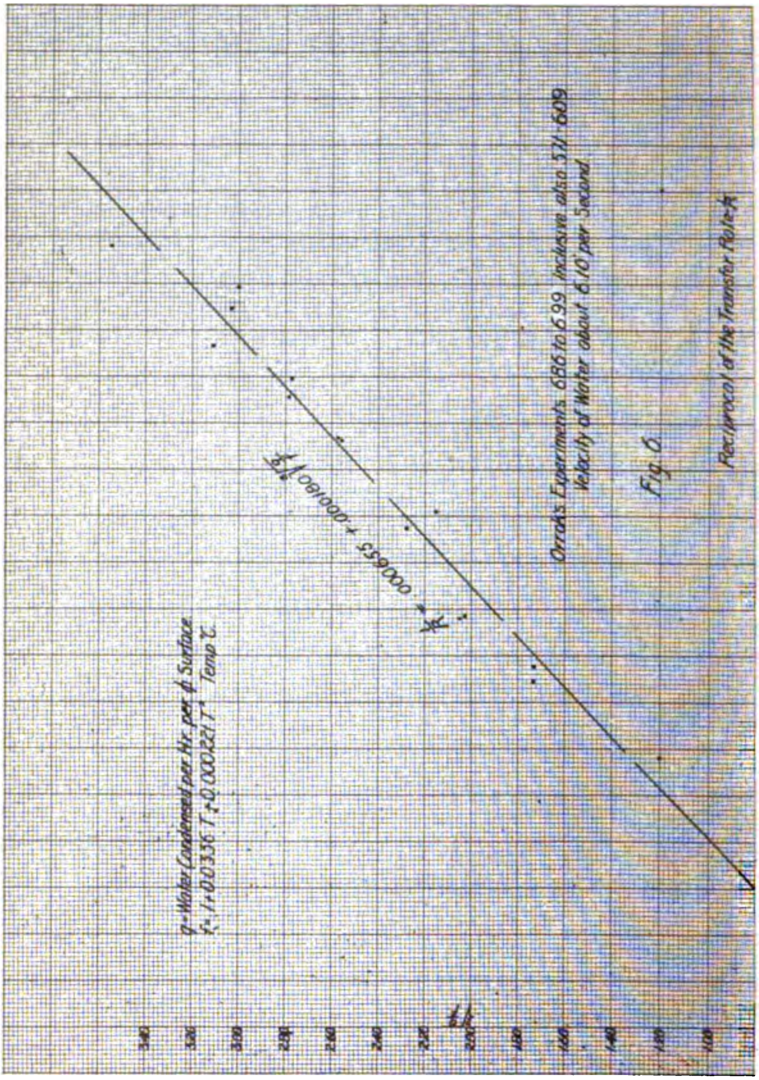
q=Water Condensed per Hr. per ft. Surface
T=1+0.0336 T+0.000221 T² Temp °C
$\frac{1}{k}$ = .000653 + .0001801/√v
Orrok's Experiments 686 to 699 Inclusive also 571-609
Velocity of Water about 6.10' per Second
Fig. 6
Reciprocal of the Transfer Rate 1/k
$\frac{q}{T}$
340
320
300
280
260
240
220
200
180
160
140
120
100
00000
00020
00040
00060
00080
00100
00120
00140

Fig. 6.

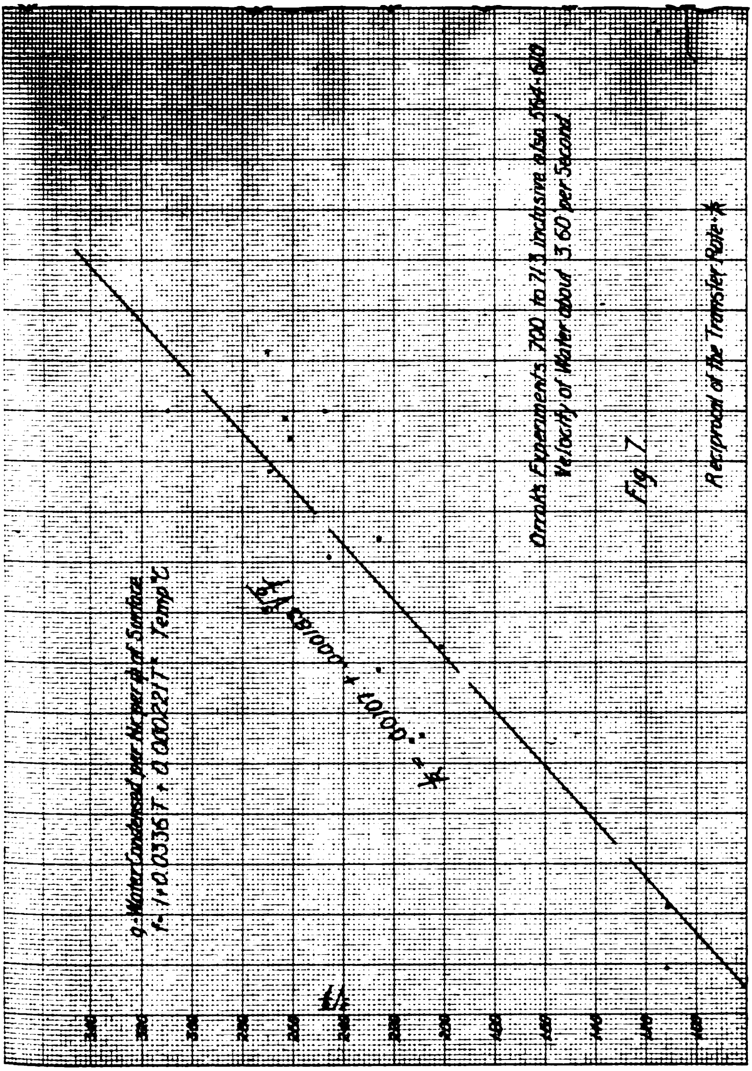
Orrok's Experiments 700 to 713 inclusive also 564-610
Velocity of Water about 3.60 per Second
Fig. 7.
Reciprocal of the Transfer Rate $\frac{1}{K}$
q-Water Condensed per Hr. per # at Surface
f-1+0.03367+0.000217 Temp °C
$\frac{t}{fq}$ = .00183 + .00107 $\frac{1}{K}$
$\frac{t}{fq}$
.00120
.00130
.00140
.00150
.00160
.00170
.00180

Fig. 7.

the agreement with the value computed from Orrok's experiments may be considered satisfactory.

I have just assigned values for all the terms that would enter into a formula for the transfer rate applicable to condensers and, with clean tubes properly arranged, experimental results should check the formula closely. If, however, the steam condensed on some of the tubes drains off on the others, the water film on the bottom tube surface must be more than it was in the experiments of Mr. Orrok. This term is of about equal importance with the water velocity term, and this effect would be noticeable in the value of the transfer rate, so that some judgment must be used in supplying this data or, in fact, any data.

The form of the transfer co-efficient is not suitable for integration, but it is a good form for practical use, and the value for *R* can quickly be determined by the trial and error method.

In conclusion I wish to refer to one more example only of heat transfer. This is from small wires exposed to an air current. It has been found that the transfer rate in this case is proportional to the square root of the velocity of flow. The motion of the gas around the small wires, however, is altogether different from that in a pipe, and there is nothing in these experiments that would in any way affect the reasoning or conclusions in this paper. The results can be applied only to very small wires, such as used in measuring wind velocity in electrical anemometers.

It was originally my intention to touch on the absorption of heat in hot stoves and regenerators, which constitute the most complicated problem in my mind presented by the subject, but the paper has grown to such length that time does not permit entering into the matter now.

DISCUSSION

Prof. Willibald Trinks:* Our Society is fortunate in having read before it a paper of the type offered by Mr. Bell. Many mistakes now made by engineers and would-be engineers could be avoided if the laws of heat transmission were better known. One feature of the paper, in particular, struck a sympa-
made in measuring
of a tempera-
es themselves.
isness, reports
el plants, giv-
stoves to four
rst figure may
g.
sion in boilers,
out still more
face; yet heat-
er may become
rying hot gases
e of refractory
the heat which
f the flue. The
g surface. The
own to all Pitts-
ng furnaces and
f the refractory
g furnaces, and
heating by con-
onsequent radia-
part.
er, there may be
able to see why
re attracting at a
ect the unit mass
system we have

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Institute of Technology, Pittsburgh.

an example of vibration, such as a solid might possess. A comet offers a suggestion for the motion of a gas. Viewed from an enormous distance it might appear as if the comet collided with the sun and then bounced back from it, when, as a matter of fact, we know that it simply passes around it. Now, why cannot the molecules swing around each other like the comet swings around the sun? If they do, one general force, that of mass attraction, in conjunction with inertia, the other general property of mass, explains the motion of molecules. Many other physical facts which are hard to explain by the molecular billiard ball theory become very much simpler by this view of matter.

A more specific statement is needed with regard to temperature. The statement that "this mean kinetic energy of motion is the same for all substances at the same temperature" is somewhat vague. It should read that the mean kinetic energy of motion per molecule is the same, etc.

PROF. C. N. WENRICH:* We ought to be very happy that we have had this subject brought before us in this fashion. The author of the paper undoubtedly considers the soil in this field quite barren, inasmuch as he stated that there was very little known.

I may disagree with the author in the way this "little" is known. I think, at least, there is just as much known on the engineering side of the subject as there is on the molecular side, because we have about as many ideas on molecules, attractive and repellent forces as we have heads. We are almost at a loss to know what the final thing will be. I would like to ask the author to make a distinction or comparison between the attractive and repellent forces. I remember seeing a statement that the attractive force had one law and the repellent another. Is it not a question as to whether a molecule is repelled by a force or perhaps attracted by another so that what seems to be a repellent force is in reality an attracting one? If the molecule is repelled to some other molecule so that the force becomes one of attraction, what becomes of the molecule? Does it stay there? The subject of radiant energy seems to be what causes, what stimulates, and what moves the molecule that we say moves and then causes some other to move or manifest its energy in some other way. It is well that the author agitates the question, for it takes courage to keep agitating, and it seems just now that one idea is about as good or bad as any other. It is easily seen that molecular movements involve an expenditure of energy in some way, and we generally dispose of the question in some such fashion as by saying that the system received energy, and hence most anything desired may take place, instead of specifying the amount and direction of this energy and stating definitely the way in which the energy is transmitted. For instance, in the question of solids transferring heat, the author states that the motion is from high to low temperature, i. e., from a hotter to a colder end. We know that this is so, and yet we can learn much by knowing exactly how this is done.

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*Professor of Physics, University of Pittsburgh.

It is perhaps interesting to note the idea of a transfer of energy by a sympathetic vibration system. As an illustration: A sound wave that travels against a piece of glass, or in fact any material, may be received on the other side in several ways. If the material has grains across the material for the air to pass through, we have a gas transfer. On the other hand, if the material is air tight, but has a period of vibration somewhat close to that of the source of sound, it will begin to vibrate, and in this way transfer the energy to the other side of the material and start a wave. This may be called a sympathetic vibration system of a transfer of energy and may in many cases be a help to explain the phenomenon. A line of tuning forks may be set into vibration by this plan, and it is not unlikely that a line of similar particles of matter can do the same thing.

If I remember correctly, it was last year that Professor Suydam showed that the exponent in Stefan's law varied as much as one and one-half at reasonably high temperatures of even eight or nine hundred degrees. This, I must admit, is a surprisingly great variation and may bear a second reading or perhaps investigation.

We talk about the molecular side of heat transfer, but, after all, I could not help but feel when reading the author's paper that when we come to measure heat, we have very little or nothing from the molecular consideration that we follow in the measuring process. As far as the molecular consideration is concerned, we might as well choose the measuring instrument as our ground for argument as anything else. Theories, of course, sound well at times, and I agree with the author that with all the theories we do have we know very little about internal heat conduction and radiation.

Could we have the satisfaction, since Mr. Bell has gotten into this molecular theory, of having him explain the fusion of ice, the heat of fusion, and the fact that the water is denser than the ice, and yet have the transfer of heat accomplished as outlined in the paper?

Mr. H. Braude: Several years ago there was quite a discussion concerning the heating of bodies by radiation. Material of a certain structure, such as magnesite, fire clay and special compounded substances, which possessed the property of radiating energy when heated to a suitable temperature, were built up in the form of plates and heated on one side, by means of gas or other fuel, to an incandescent heat. The side of the body opposite that which was being heated radiated energy to the body or substance to be heated.

The following claims were made for this process of heating by radiation only: First, a very high temperature can be obtained —in fact, a higher temperature than the original source of heat.

The plate acted like an electrical transformer where the temperature energy is converted tc high temperature energy.

It was claimed further that the temperature could be controlled very closely by this means.

The promoters predicted great things for this process of heating, but I have not met with any practical applications. What is the reason that this method of heating, which appears to be theoretically sound, and was thoroughly tested out, has not found a wider commercial application?

Mr. Henry Kreisinger:* I was more fortunate than most of you by having had the opportunity to see Mr. Bell's paper in advance of this meeting. I have read it with interest and pleasure, and I wish to congratulate Mr. Bell on his success in handling this rather intricate mathematical subject in plain English.

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*Fuel Engineer, U. S. Bureau of Mines, Pittsburgh.

I was especially pleased with the paper because Mr. Bell agrees in general with the conclusion arrived at in the government publications. Most of the general formulas that Mr. Bell presents in his paper have appeared in the bulletins of the Bureau of Mines. This is particularly true of Stefan-Boltzmann radiation law and Osborn Reynolds' formula for heat convection and their application to steam boiler problems. In one of the publications of the Bureau, namely, Bulletin 18, is an abstract of the now famous Reynolds' paper, first published in 1874. In the same bulletin are also thorough abstracts of the paper of T. E. Stanton, published in 1897, and of John Perry, to whom probably belongs the honor of bringing to light Reynolds' paper after it had been buried over twenty years. Bulletin 18 has been criticised by prominent engineers for upholding Reynolds' formula; therefore, I feel gratified because Mr. Bell thinks so well of the formula, and has been able to reduce it to a simple form directly applicable to practical problems. Mr. Bell contributes some valuable constants experimentally determined by himself, which are applicable to a wide range of conditions.

I wish to tell you briefly what the government has done along this line, what it is now doing and what are some of the results. The study of the heat transmission was started in St. Louis about ten years ago, when some of the work now being done by the Bureau of Mines was under the Geological Survey. It was started as a side investigation, and for several years it was carried on intermittently only when the regular work permitted.

The first experimental work was done with small tubular boilers having tubes three-sixteenth to five-sixteenths of an inch in diameter and eight to sixteen inches long. The purpose of these experiments was to study the heat transmission by convection. While the results of these experiments were not directly applicable to commercial problems, they showed that Reynolds' conception of the subject and his formula were nearer to the truth than any other formula. These experiments were criticised, perhaps justly so, because they were made with toy boilers. This fact was realized by the men who made these experiments, and therefore no constants were offered for the solution of commercial problems. The experiments, however, did some good, because they started general interest in the subject, and pointed out the direction along which investigation should be carried. It should be stated here that Mr. Bell's constant *R* for two-inch tubes is only about 30 percent smaller than the same constant for these small boilers having tubes only about 0.2 of an inch in diameter.

About three years ago the Bureau of Mines started similar investigations on a large tubular boiler 20 feet long and which will have in turn several commercial sizes of tubes. The boiler will be also varied in length. Through the tubes of the boiler are passed products of combustion resulting from burning natural gas. The air and the gas used in the combustion are measured, and the temperatures of gases entering and leaving the tubes of the boiler are determined. These measurements give one way of determining the heat absorption by the boiler. The heat absorption is also determined by weighing the water fed into the boiler, measuring the feed water temperature and determining the quality of steam. The steam is made under 120 lbs. gage pressure. Thus two independent methods of determining the heat absorption are used. The experiments with this boiler are well under way; results so far obtained agree with those obtained with the small boilers. It is planned to investigate with this same apparatus the effect on heat absorption, of retarders, eddy rings, cores in tubes, scale on water side, and soot on the gas side of the tubes.

In many commercial problems the heat is transmitted by convection and radiation at the same time. This is particularly true in steam boilers. Attempts were made to devise a formula which would express the quantity of heat transmitted to the boiler by both of these modes of heat transmission combined. However, the best way to get at the total quantity of heat in such a problem is the way Mr. Bell suggests, and that is, to analyze the problem as to the modes of heat transmission, figure each rate separately, and add the results together.

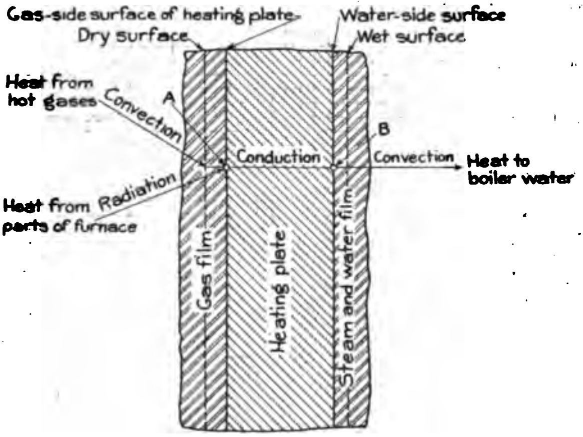
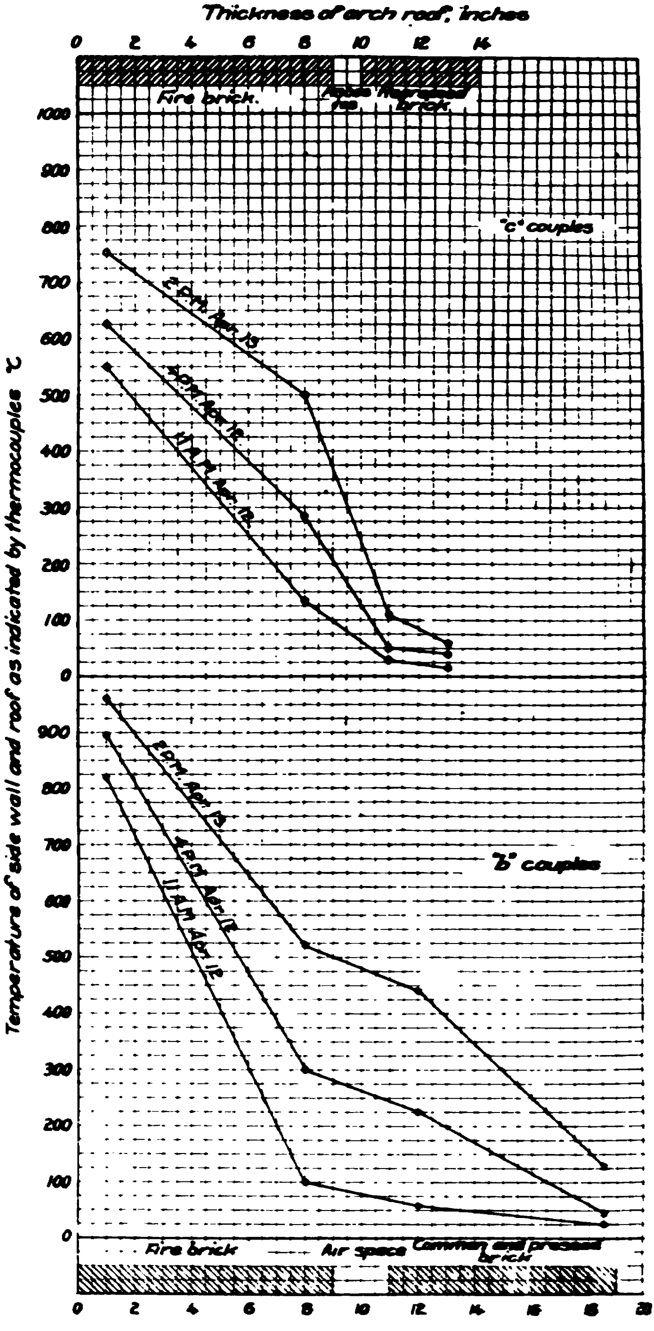


Fig. 8. Diagram showing the path of heat travel from the hot gases and hot parts of the furnace through the heating plate into the boiler water.

Figure 8 illustrates the problem of heat transmission in steam boilers, and shows why sometimes the rate of heat transmission is expressed by formulae containing the square of temperature difference. The diagram illustrates a cross section of a heating plate, to which on one side adheres a film of gas and on the other a film of water. From the hot fuel bed, furnace walls, and the flames, heat is radiated directly to the gas side surface of the plate. From the hot products of combustion heat is carried by convection into the gas film, and through part of the film and through the plate by conduction to the water. According to Reynolds, the rate of heat convection is proportional to (a) the rate at which hot particles from the moving stream of gas enter this film and cold gas particles leave it, and (b) the difference in temperature between the hot particles of gas entering the film and those leaving the film; the temperature of these leaving particles is the same as that of the film. The average temperature of the film is considerably higher than the gas side surface of the plate, because heat must pass from the film to the metal by conduction, and inasmuch as the conduction in gas is a slow process, high temperature drop is necessary. In any one problem, the temperature difference between the moving gases and the gas film is pro-



[illegible] Temperature drops through a furnace wall containing a two-inch air space, and a wall containing a one-inch layer of asbestos insulating material.

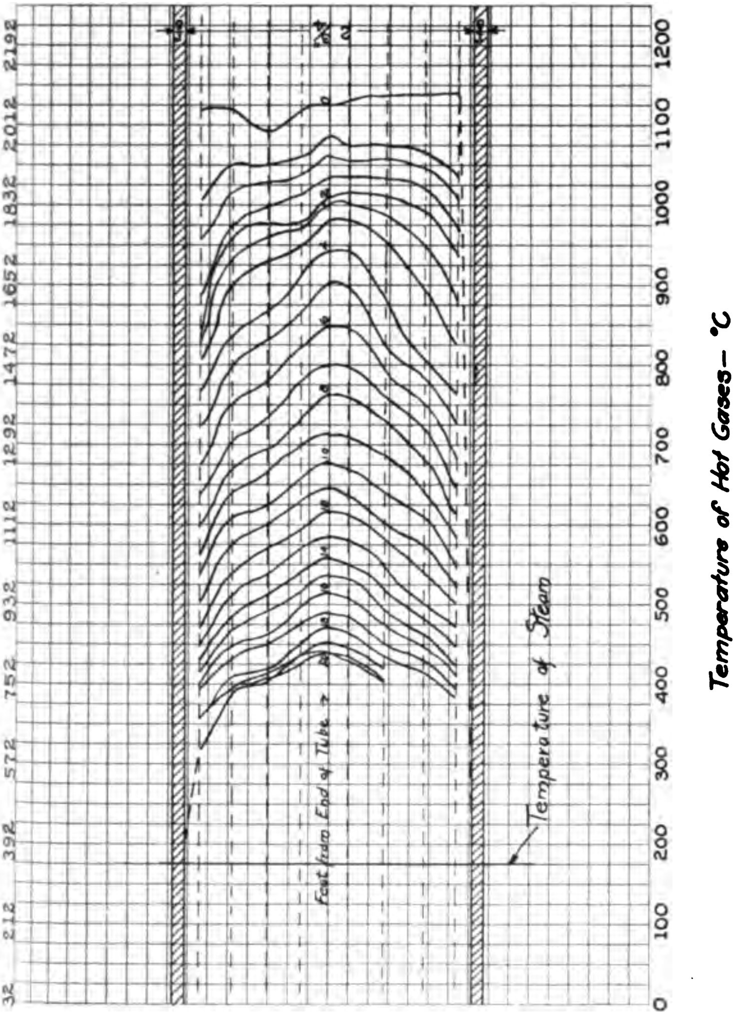


Fig. 10. Variation of temperature of gases in a boiler tube 2¾ inches in diameter.

portional to the temperature difference between the moving gas and the gas side surface of the plate. Therefore the latter difference can be used in the computation of the quantity of heat transmitted by convection.

The rate of heat radiation follows the Stefan-Boltzmann law and is proportional to the difference of the fourth power of the absolute temperatures of the furnace and the heating plate.

Thus the rate of convection contains the temperature factor as first power, and the rate of radiation as fourth power. If the two rates are combined, the temperature factor may appear as third power or as square, depending whether the radiation or convection predominates. The formula in which the rate of heat transmission is proportional to the square of the temperature difference, probably due to Rankin and upheld by Professor Kent. can indeed be applicable only to very special cases of combination of the radiation and convection.

Figure 9 gives another illustration why the different modes of heat transmission should be given separate and full consideration. The figure shows the temperature drop through two kinds of furnace wall construction, one having a two-inch air space and the other having the air space replaced by one-inch layer of insulating material. There are shown three temperature curves for each construction. They show the changes of the temperatures as the walls are heated. The highest curves of each group show the temperature drops when condition of equilibrium was reached after about 27 hours of heating. The air space is used in the furnace wall construction because air is a non-conductor of heat and is expected to prevent heat dissipation through the wall. It fails entirely in this object, because heat passes across the air space easily by radiation. The comparison of temperature drop across the air space and the one-inch layer of insulating material shows that the latter is much better construction so far as prevention of heat losses from furnaces is concerned. The designer of the air space evidently thought only of the low heat conductivity of air and never gave the radiation law any consideration. Since air space was effective in refrigerators it was expected to be effective in furnace construction.

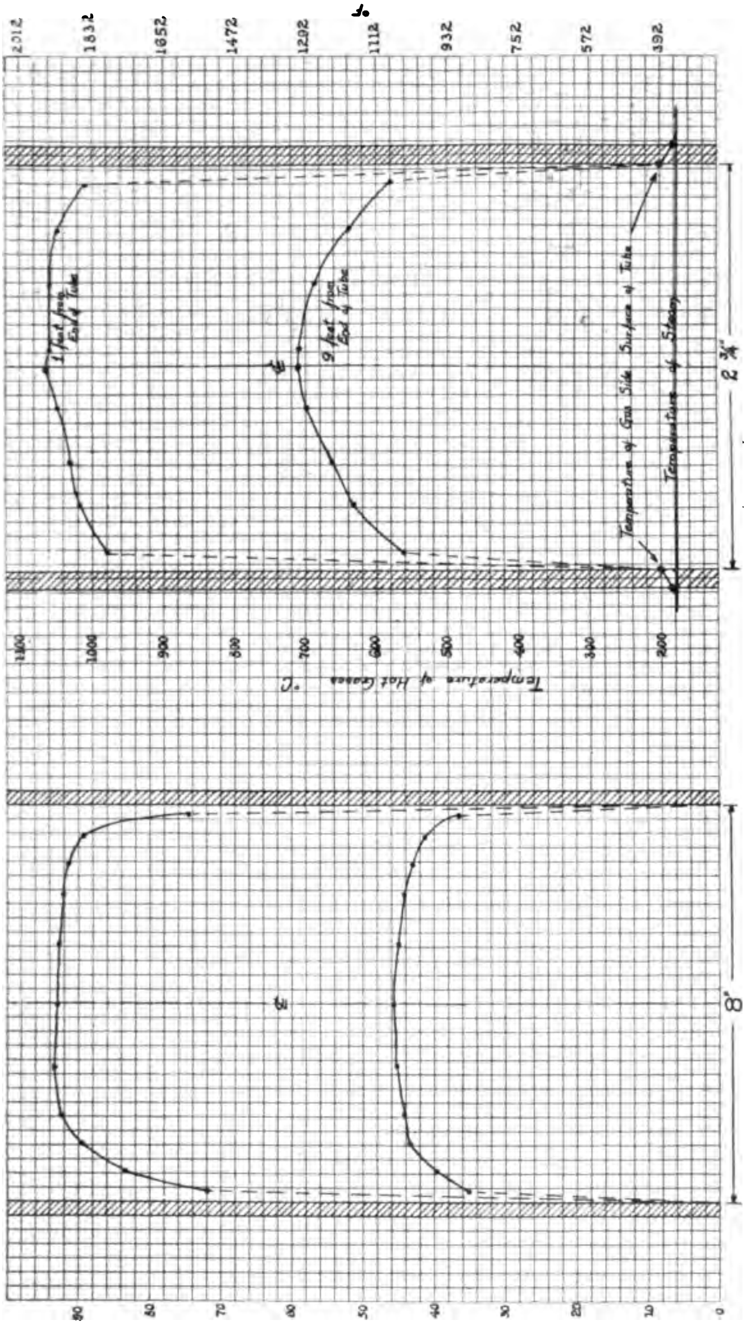


Fig. 11. Comparison of temperature and velocity of gases in a boiler tube.

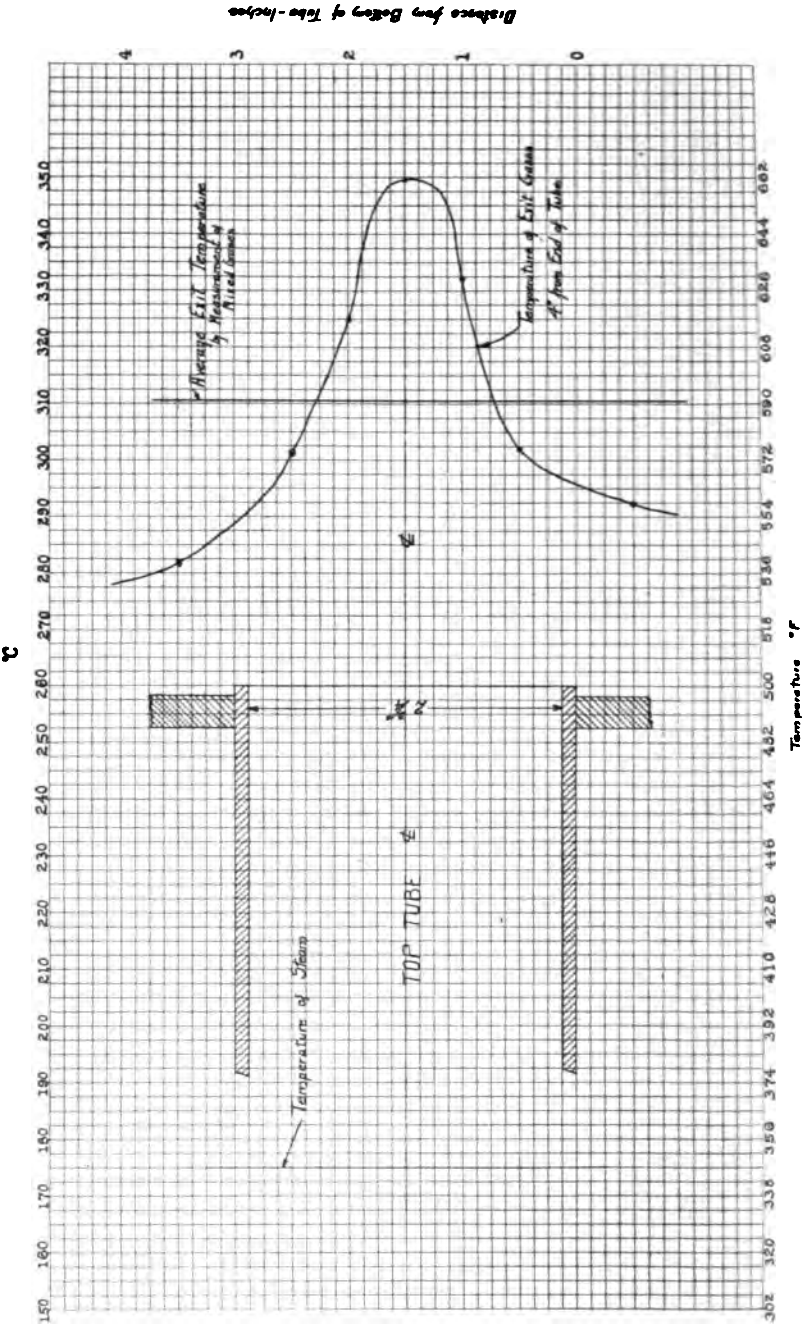


Fig. 12. Temperature of gases leaving a boiler tube.

Figure 10 gives temperature measurements in a boiler tube at nine points on a vertical diameter and for every foot of its length. The temperatures were taken with an exposed platinum and platinum-rhodium couple made of wires 0.012 of an inch in diameter held in the different positions by special guides. Of course, we know that this indicated temperature is somewhat lower than the gases due to radiation error, but this error is the same for all points at the same cross section. The figure is intended to show the variation of temperature along the diameter and also along the length of the tube. These measurements show that the temperature at one cross section stays up to within one-eighth of an inch of the tube surface, so that the biggest drop must occur within a short distance of the surface, that is, within the film of gas where heat travels mostly by conduction.

Figure 11 shows what probably happens within the tube. The diagram on the right shows two of the temperature curves from Fig. 10, and the diagram on the left the velocities of air in an eight-inch pipe as measured with a Pitot tube. There is a marked resemblance between the velocity and the temperature curves. In both cases the biggest drop is within a short distance from the surface of the tube, and there is little doubt that the drop in velocity is the cause of the drop in the temperature. That is, as the velocity decreases, the transfer of heat by convection is reduced and the heat has to be transmitted by conduction, which in a gas is a slow process, and therefore a high temperature difference is required.

Figure 12 shows the temperature of gases at the exit end of the tube. The temperatures were taken four inches from the boiler head, on a vertical line passing through the center of the tube, at the points indicated on the curve. The interesting part of this chart is the relation of the average temperature of the gases after they are mixed to what it is in the different rings of the gases flowing out of the tube. The indications are that the farther the gases flow in the tube from the furnace end, the greater is the variation in temperature along a diameter at any one cross section; that is, there seems to be less mixing of the different rings of gases, their tendency being to flow in parallel streams.

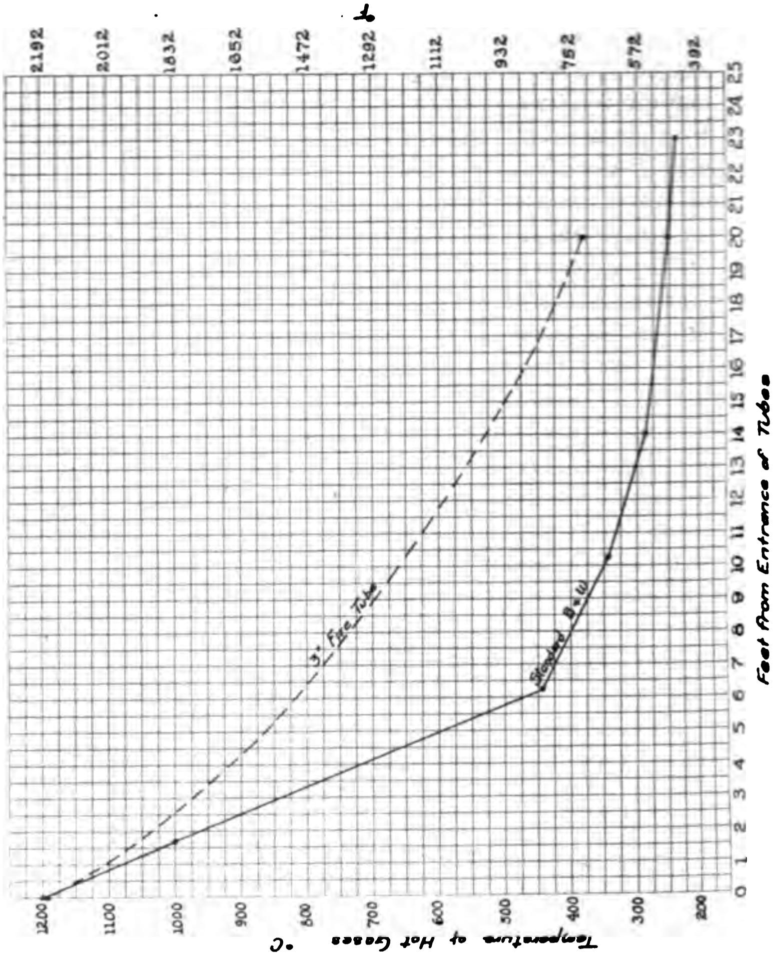


Fig. 13. Comparison between temperature drop of gases flowing through a B. & W. boiler and through a fire tube boiler.

Figure 13 shows a temperature drop along the path of gases in a 2¾-inch boiler tube, and a similar temperature drop through a cross-baffled B. & W. boiler. Both of these curves are from actual measurements, corrected for radiation error. The corrections were made by making measurements with different sizes of thermocouples, and from the results thus obtained temperatures for zero diameter thermocouple were determined. The lower curve indicates that the heat transfer is much more rapid in the first part of the B. & W. boiler than it is in the tubular boiler. This is probably due to more violent mixing of the gases caused by their flow across the boiler tubes. This bears out Mr. Bell's statement that R in his Equation (1) is greater for B. & W. boiler than it is for tubular boiler.

Figure 14 is intended to explain why small tubes in a tubular boiler are more efficient than large ones. The figure shows a cross section of a 4-inch tube and a 2-inch tube. The average distance of any gas particle A from the surface of the 2-inch tube is one-half of that in the large tube; therefore the particles of hot gas come in contact with the tube surface about twice as rapidly in the small tube as in a large one. As a result of this, the small tubes are more efficient as heat absorbers than the large tubes. That is, if the same weight of gas at the same temperature is pushed through a 4-inch and a 2-inch tube of the same length the small tube will absorb more heat than the large one. This fact also follows from Mr. Bell's Equation (1).

Figure 15 shows the relation between the diameter of a thermocouple and the temperature indicated by it when inserted in a stream of hot gas at 1012° C., and surrounded by surfaces at 700° C. The four points are the averages of several readings. The curve has a definite equation derived from the radiation and convection formulas. A curve of this type has been used for obtaining the true temperature of gases of Fig. 13.

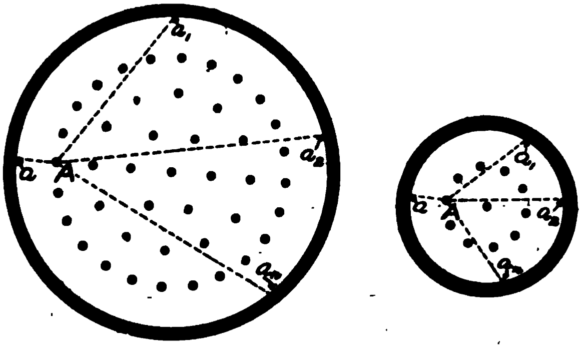


Fig. 14. The average distance of gas particles from the heat-absorbing surface is twice as large in a four-inch tube as it is in a two-inch tube.

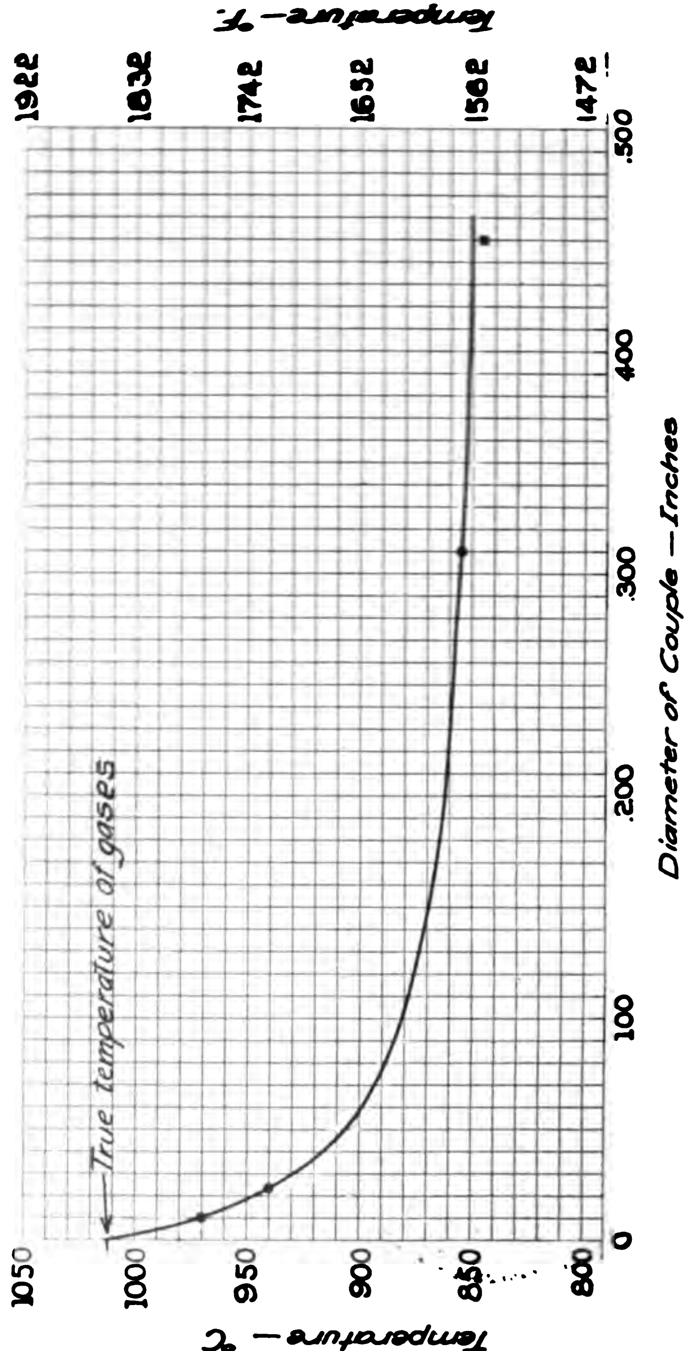


Fig. 15. Relation between the diameter of a thermocouple and the temperature the couple indicates, when placed in a stream of hot gases surrounded by cooler surfaces.

Mr. J. R. Mason:[†] I would like to ask Mr. Bell whether or not he has been able to determine, in his experiments on heat transmission in boilers, whether the transmission is more rapid with boilers such as Babcock & Wilcox type, or the Stirling with semi-vertical tubes? According to Professor Perry's theory, the great essential requirement is to have a close, scrubbing action of the gases over the heating surface, and it does not make so much difference as to the mode of travel.

Mr. John E. Bell:[*] It was not my intention to emphasize the physical side of this paper. The discussion of the constitution of matter was for the purpose of giving a foundation for an understanding of how heat is transferred by conduction and by radiation. The theory given is no longer an hypothesis, and during the last three years has been accepted generally by physicists in all countries. Professor Trinks brings up the question as to why molecules should attract at one distance and repel at another. This is fully explained by the electron theory. The molecules are electric doublets, and when two of them are in one position they attract. In other positions they repel. The encounter between two molecules in motion is assumed to be of the character he describes. At the same time it is called a collision. For the purpose of mathematical expression the billiard ball theory leads to the same results as assuming one molecule to move around another in collision. I used the term as used by Jeans in his "Dynamical Theory of Gases," where both forms of encounter are fully investigated. Professor Trinks calls attention to the statement made in the paper, "this mean kinetic energy of motion is the same for all substances at the same temperature." I have changed this to read "this mean kinetic energy of motion of the particles is the same for all substances at the same temperature." This mean values applies to the electrons as well as to the molecules, also to any free atoms that may be present.

Professor Wenrich questions somewhat Stefan's law. For full radiance I do not see how it is possible for this law to be anything but a statement of fact. Boltzmann's mathematical deduction from the electro-magnetic wave theory and the second law of thermodynamics establishes it beyond question, as other deductions from this same investigation have been proved correct by the most exacting experiments. Stefan's law would be hard to prove or disprove by a direct experiment.

[†] District Manager, The Wickes Boiler Co., Empire Bldg., Pittsburgh.

[*] Author's closure.

With reference to Professor Wenrich's question, "Could we have the satisfaction, since Mr. Bell has gotten into this molecular theory, of having him explain the fusion of ice, the heat of fusion and the fact that water is denser than ice and yet have the transfer of heat accomplished as outlined in the paper?"—the fact that there is a latent heat of fusion shows that there is a change in the molecular aggregation. There are further changes in this molecular aggregation as the pressure is increased and temperature decreased and a number of different forms of ice are now known. An actual molecule may be an aggregation of a number of simpler ones. From the character of their construction this must necessarily be true. Assuming that it is true, there is nothing I have said that would be modified by the consideration that Professor Wenrich suggests.

Answering Mr. Braude's question, I would say that it is impossible for any plate exposed to hot gases under any circumstances to obtain a higher temperature than the gas itself. Gas that burns with a clear flame radiates very little heat, and if the flame plays on a refractory surface to all intent and purposes a higher furnace temperature is produced; but this increase in temperature is deceptive, it is due entirely to the presence of radiant heat. Professor Trinks refers to this same question, expressed in a different way in his discussion.

Mr. Kreisinger's discussion will form a valuable addition to the paper. I do not believe, however, that he correctly states the history of the subject. The ordinary transfer equations given in the paper cannot be attributed to anyone, as any pupil in a class in calculus could deduce them. They were put in simply for the purpose of reference. The whole theory depends on the determination of the value of the transfer rate as affected by velocity and temperature. Professor Reynolds called attention first to mass-flow as it appears in the transfer rate, but he gave neither a valid experimental nor scientific explanation, and since he reached the conclusion that the flue gas temperatures in a boiler should be independent of the capacity developed, it is not to be wondered at that engineers gave little attention to his paper. Professor Perry brings the matter up in a text book and in a way that would no more influence an engineer than Professor Reynolds' paper. It was some time before this law was demonstrated to hold with reference to boilers, for the reason that the value of the constant a is equal in importance to the other term, and both Professors Reynolds and Perry seem to believe that its value could be neglected. As far back as 1902 I tried to check up Perry's formula by actual boiler tests, with very unsatisfactory results, and it was only after I assigned a large value to the constant part of the transfer rate that I was ever able to get consistent figures. The variation of b with temperature is quite important in many cases, and neither Reynolds nor Perry referred to this. I think this whole subject has been developed from the experimental side and that theory has had little, if anything, to do with it.

Replying to Mr. Mason's question, I would refer to the statement made in the preceding paragraph, namely, that it is very difficult to determine actual transfer rates from boiler tests. The effect of radiant heat and the furnace arrangement is just as important as the absorption of heat by gas contact with the tubes. Any boiler can be baffled so as to give a high gas velocity, and consequently a high transfer rate, so that with a decent furnace arrangement very good efficiency will be developed on test. I do not believe Mr. Mason's question admits of a direct answer.

THE DESIGN OF SYMMETRICAL HINGELESS CONCRETE ARCHES[†]

By VICTOR H. COCHRANE[*]

SYNOPSIS

The object of this paper is to develop a series of formulas and diagrams for use in making preliminary and final designs for symmetrical hingeless concrete arches in accordance with the elastic theory.

In Part *I* the difficulties and uncertainties involved in applying the elastic theory are enumerated; and approximate, rather than theoretically exact, methods of design are advocated. It is pointed out, however, that the variations from exactness due to the approximations proposed herewith are of little consequence in comparison with those due to certain approximations in common use. The factors affecting the values of the thrusts and moments are briefly discussed and the proposed methods of design are outlined.

In Part *II* the most desirable geometrical form for the arch axis is considered, and equations are derived giving approximately the best shape of axis for both open spandrel and filled spandrel arches.

Part *III* contains a discussion of the proper thickness of the arch ring in the haunch for given thicknesses at crown and springing. A series of typical arches is chosen applicable to any span length, rise-ratio, thickness at crown and springing, or manner of loading. The characteristics of these typical arches are then given, including the relative thicknesses, the areas of vertical faces, the lengths of the half-axes, the values of the constant $\Delta s \div I$ in terms of the moment of inertia I_0 at the crown, and the location of the centers of divisions such that the ratio of the length of each division to the moment of inertia of the section at the center of the division is equal to the constant $\Delta s \div I$.

[†] This paper was published in the November, 1916, issue of the Proceedings, vol. 32, No. 8, pp. 647-718.

[*] Engineer of Bridges, City of Kansas City, City Hall, Kansas City, Mo.

In Part *IV* influence line diagrams are given for the crown and springing sections of both open and filled spandrel typical arches, applicable for ordinary cases to any span length, rise-ratio, or live load. Several interesting features of these diagrams are discussed, including the four typical loadings producing maximum moments, and the variation in moments and thrusts with respect to the rise-ratio and also with respect to the ratio of springing thickness to crown thickness.

Part *V* contains formulas giving the values of the maximum thrusts and moments at crown and springing due to live loads, temperature variations, and the shortening of the arch. Approximate formulas are given for the dead load thrusts. These formulas, like the influence line diagrams, apply to both open and filled spandrel arches of any span length, rise-ratio, or live load. The steps required in designing an arch by means of the formulas are enumerated.

In Part *VI* there is developed an approximate method for correcting the maximum moments in case the actual arch axis deviates considerably from the assumed axis.

In Part *VII* are given five examples showing the application of the formulas and diagrams. Computations by other methods for four of the arches considered are to be found in engineering literature, and the results by these methods are stated for the sake of comparison.

Part *VIII* contains a list of cases in which it is believed the use of the formulas and diagrams herewith will be found to effect a great saving in time and labor.

DISCUSSION*

Prof. William Cain:† This paper is a valuable contribution on the design of arches and will be especially appreciated by the practical engineer. It has evidently entailed immense labor in the preparation, and the results are not only instructive, but should prove very useful in design.

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*This paper was published in the November, 1916, issue of the Proceedings, vol. 32, No. 8, pp. 647-713.

†Professor of Mathematics, University of North Carolina, Chapel Hill, N. C.

The writer is in entire accord with the author, in view of the many approximate assumptions made in deriving working formulas, that an approximate solution, if sufficiently close, is desirable. The author has summarized the assumptions on p. 650, none of which is exact or certain. Of these, the slight yielding of the foundations, shrinkage of concrete in setting, and temperature changes, are the most uncertain features; to which may be added the increase of heat due to the setting of the concrete.

It is certain that the arch ring throughout—particularly for an earth-filled arch—is never of a uniform temperature, as necessarily assumed in the theory; further, the amount of temperature change to allow, for either an open spandrel arch or a filled spandrel arch, is uncertain, though recent experiments by Messrs. C. S. Nichols and C. B. McCullough‡ have added materially to our knowledge on this subject. The experiments were conducted on two earth-filled arches at Ames and Des Moines and the conclusion was drawn that the effective temperature range in a mass of concrete of less than 5 or 6 feet in thickness is about 75% of the mean atmospheric variation. Doubtless the percentage would be increased for an open spandrel arch. It was found, too, that high temperatures were obtained in a few days from the setting of the concrete, and the authors conclude that 100° F. may be taken as a safe average of the final temperature. Is this range, from 100° F. to the lowest temperature subsequently attained, to be used in computing the stresses due to a fall of temperature? To give a definite reply to this question and to the allied one, as to what shrinkage stresses should be provided for, is impossible in the present state of our knowledge.*

It is possible, but by no means certain, that the behavior of an arch ring on the forms is as follows: assuming that the ends of the continuous steel ribs are fixed in rigid abutments; then when the arch is poured, there is a rapid rise in temperature which tends to cause the steel to rise, which is counteracted by the weight of the still, partially plastic concrete, in which

‡Bulletin No. 30, Iowa Engineering Experiment Station.

*See remarks in Hool's "Reinforced Concrete Construction," Vol. III, pp. 35-41, on these subjects.

there is, as yet, but little stress. At the time of highest temperature, the elasticity of the concrete is imperfect, so that the total fall of temperature from this high limit to the lowest attained in a year or more cannot be used as a basis for computing stresses due to either temperature changes or shrinkage, since such computations assume an arch with the same modulus of elasticity throughout the period. As the setting of the concrete goes on, from day to day, the temperature eventually falls to normal; and, throughout this period, the steel steadily makes the effort to regain its original position. This is aided by the shrinkage of the concrete of the arch, so that at a certain stage of the setting the steel has nearly its original position, though both steel and concrete are under unknown initial stresses. If these stresses are small or negligible, it would seem that the temperature of the concrete at this stage could be approximately treated as the mean temperature from which to reckon temperature rise or fall for computing stresses due to temperature changes; further, from this stage, the additional shrinkage is all that should be allowed in computing shrinkage stresses. The difficulty lies in fixing this stage, but it would appear to be when the arch was still above the air temperature.

The so-called mean temperature, in present practice, is arbitrarily assumed and a rise and fall of temperature of about 40° F. is often specified for computing stresses due to temperature changes. It would seem more logical to allow for a greater fall than rise of temperature if the arch is poured at this mean temperature—say a rise of 20° and a fall of 60°. As to shrinkage stresses, they are at present ignored, as the shrinkage coefficients on *actual arches* have not been ascertained.

In view of all the uncertainties referred to, the author's claim that an approximate solution is justified seems sustained. But if an approximate solution is used, which may be in error a certain per cent., then it would appear that smaller unit stresses for steel and concrete should be specified.

The author (on pages 651, 704) properly cautions against the use of parabolic arch formulas for all kinds of arches and calls attention to the fact that the arch shortening effect is different for each different combination of loading and should be computed for each such combination in turn. A word may not be amiss as regards the shortening, resulting from the normal component of the stress on each radial section.

Let the axis or the neutral line of the arch be divided into n parts, each part having the same horizontal projection Δx. Let the length along the axis of any one part be denoted by Δs and suppose the tangent to the axis at the center of Δs to make the angle α with the horizontal and that the unit normal stress on a radial section equals f. Then, if E is the modulus of elasticity of the concrete, the shortening of the arch for the small length Δs, is approximately,

$$\frac{f\Delta s}{E}$$

and its horizontal projection is,

$$\frac{f\Delta s \cos \alpha}{E} = \frac{f\Delta x}{E}$$

The sum of such quantities for the entire arch is the shortening of the span, which can be represented by,

$$\frac{1}{E} \Sigma (f\Delta x) = \frac{n\Delta x}{E} \frac{\Sigma (f)}{n} = \frac{l}{E} \frac{\Sigma (f)}{n}$$

where l is the span of the neutral line and $\Sigma(f)$ is the sum of the normal unit stresses, each taken at the mid-point of each portion Δs of the axis, and

$$\frac{\Sigma (f)}{n}$$

is the mean stress, thus obtained, for the n divisions, or for the entire arch. It thus follows, for accuracy in finding the mean stress, the *span* must be divided into *equal* parts and verticals erected at the points of divsion to ascertain the corresponding divisions of the axis.

The author discusses (on pages 654-656 and page 686) two schemes for laying out the most desirable arch axis. In the first, the arch axis is made to coincide with the equilibrium polygon for dead loads only, the thrusts passing through the centers of crown and springing as for a three-hinged arch; by the second, the axis is determined in the same way, only using a load consisting of the dead load combined with one-half of the live load over the entire span. By the elastic theory, in either case, the thrusts at the crown and springing will pass through the centers of the radial sections there and the thrust at the crown is horizontal, since the loading is symmetrical with respect to the crown. The moment about any point of the axis is zero, for either case, for the loads as stated.

To consider further the case where the arch axis coincides with the equilibrium polygon for dead load and one-half the uniform live load covering the entire span (arch shortening being neglected); for a point P on the axis, let us call M_D, the dead load moment and M_1, the maximum positive moment for the full live load per foot, covering a length (say) l_1 of the span, and M_2 the maximum negative moment for the full live load per foot, which covers the remaining length l_2 of the span (as is well known), the elastic theory being employed to find M_D, M_1 and M_2. Then by this theory, when only half the full live load per foot of length is employed, the maximum positive and negative live load moments are

$$\frac{1}{2}M_1 \text{ and } \frac{1}{2}M_2$$

when the live load covers the same lengths l_1 and l_2 respectively.

Since P is on the axis,

$$M_D + \frac{1}{2}(M_1 + M_2 = 0)$$

$$\therefore M_D = -\frac{1}{2}(M_1 + M_2)$$

When the full unit live load covers only the length l_1, the total moment at P, for dead and live loads, is

$$M_D + M_1 = \frac{1}{2}(M_1 - M_2)$$

reducing by the previous equation.

When the full unit live load covers only the length l_2, the total moment at P, for both dead and live loads, is

$$M_D + M_2 = -\frac{1}{2}(M_1 - M_2)$$

or, numerically the same as for the preceding case. Also, since M_2 is negative, $(M_1 - M_2)$ is an arithmetic sum.

The above conclusion justifies the author's statement, for this case (page 686), that the maximum moments due to live and dead loads are equal to half the arithmetic sum of the live load (maximum) moments as determined by the influence lines.

Making the arch axis coincide with the equilibrium polygon for dead and one-half live loads would seem to be best for arches of large rise-ratio, since the stresses due to temperature changes and arch shortening are comparatively small; but for the flatter arches, the high temperature and axis-shortening stresses will nullify any advantages resulting from this plan and the first mentioned seems the better one.

Since the dead load equilibrium polygon for a segmental circular arch—the axis being the arc of a circle—for rise ratio less than one-sixth, say, approaches so near the axis, may not the circular arch be used economically for such flat arches? Perhaps the author can indicate the limit of rise-ratio, for less values of which the circular axis would suffice.

It is indeed fortunate that the variation in dead load, as found for actual, well-designed arches, follows the simple laws stated by the author, for the equations for thrusts and neutral line, take on simple algebraic forms.

Figure 4, showing the minimum thickness of arch ring everywhere for equal maximum stresses, is very instructive. It leads to the conclusion (page 664) "that it is unnecessary to compute the stresses in any but the crown and springing sections." This seems true, and it is one of the most important points brought out in the paper, especially from the labor-saving standpoint. The higher temperature changes now specified, as compared with those used some years back (when they were often ignored altogether), but emphasizes the truth of the statement. Also, when sufficient scientific knowledge is available to deal with shrinkage stresses, the argument will be all the more convincing. To reduce temperature stresses, the thickness of the arch ring should be made as small as possible and the author shows that it can remain nearly constant from the crown one-fourth of the way to the springing.

The division of the arch axis into parts such that

$$\frac{\Delta s}{I}$$

shall be constant, can be effected in three ways with facility:

(1) by the method of "equal areas," used by the author,*
(2) by the neat isosceles triangle method,†
(3) by the trial and error method used by the writer.‡

As the writer introduced the method of making

$$\frac{\Delta s}{I}$$

constant, he may be permitted a word as to method (3). It does not require drawing the I curve or the $I \div I$ curve, though parts of it may be drawn as the work proceeds. The tentative method proceeds rapidly except for two or three of the longer divisions near the springing. If the first trial gives

$$\Delta s_1 + \Delta s_2 + \ldots . + \Delta s_n,$$

in excess or deficient by an amount d, it is found to be sufficiently accurate to divide d between the several divisions in proportion to their length and lay off the new lengths Δs_1, etc., in order. No second trial is needed.

By the area method (1), each "equal area" is assumed to be a trapezoid, which introduces some error over a few of the divisions. The method (2) is free of error, if such a large scale is used that distances can be measured accurately to tenths of a foot. Both methods (1) and (2) require the curve to be very accurately drawn and both are tentative methods. It is likely that the beginner will have least difficulty with method (2). As the thrusts and moments are determined more accurately the greater the number of divisions, a larger number than 10 for the half arch is desirable—say 14.

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*First given in Marsh and Dunn's Manual, 1908.

†First given by A. B. White in Engineering News, Jan. 28, 1909. See the construction in Hool's "Reinforced Concrete Construction," vol. III, p. 34.

‡See Cain's "Solid and Braced Elastic Arches," 2nd Ed., 1909, p. 34 or p. 128.

The author's influence lines (Figs. 7-18) are of great value. They lead to Fig. 19, showing mean typical loadings for maximum moments at the crown and springing. The writer was gratified to find that these loadings were precisely what he had previously obtained for maximum *moments*.*

The loading for maximum *stresses*, for the simple circular arch examined, was for the crown, 0.4 span, and for the springings, 0.4 span and 0.65 span, respectively, though of course these lengths would be less for a thinner arch, approaching those for maximum moments for a very thin arch. For a comparatively thick arch, it would appear that the loading for maximum stresses should be tried to find out how much such stresses exceed those for maximum moments.

From the regularity of the curves (Figs. 7-8) it seems possible to derive their equations with a parameter r (constant for any one curve) and a variable k. It would be interesting to know if the author derived such equations; also, the method of deriving the formulas (page 687, Plate I).

The reasoning in Part VI, pages 690-693, is correct. The assumption that "the arithmetical sum of the moments is constant," seems, however, to be a very rough hypothesis on which to base formulas; nevertheless, the results, as shown in the numerical example (page 708), where the arch axis lies considerably above the dead load equilibrium polygon, lead one to infer that, for cases where the axis and polygon are nearer together, the approximation may be sufficiently near for practical purposes.

The author gives, on page 689, a clear *resume* of the method to follow in designing arches, using his methods and formulas, and, in subsequent pages, a number of numerical applications, showing the closeness of the results to those given by a more exact analysis.

The first thing in arch design is to assume a thickness of the arch at the crown. A promising formula, with diagrams, has very recently been published,† giving the crown thickness for both railroad and highway arches. It is the only formula of the kind that is founded on a rational basis—utilizing, too, certain results from actual designs—and, presumably, should prove useful.

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*Solid and Braced Elastic Arches, 2nd Ed. (1909), p. 158. As supplementary to Chapter V of this book, see Trans. Am. Soc., C. E., vol. LXXVI (1913), p. 133, on "A Shortened Method in Arch Computation."

†Engineering News, Nov. 9, 1916, "New Formula for the Crown Thickness of Arches," by Joseph P. Schwada.

With the crown thickness and the thickness ratio u_s, decided on, the author's methods lead, comparatively quickly, to a correct design and to a close approximation to the thrusts, moments and maximum stresses at crown and springing, for dead and live loads, temperature variation and arch shortening. Of course, the arch can be afterwards tested by the more exact method, if desired, and more exact maximum stresses, for the proper position of the live load, obtained; but, even then, the short method of the author will always prove a boon to the engineer in laying out the preliminary design.

Thousands of arches have been designed in this country for loading not placed in proper position for maximum moments diagrams and discussion along these lines will aid in inducing a better practice.

To locate a pressure line in an arch, it is unavoidably assumed, in the elastic theory, that the concrete can resist the tension in any section caused by the loading. It is generally difficult to design an arch, considering the large temperature variations now considered advisable, such that, at a few sections, the tensile strength of the concrete is not exceeded; whence, as in the case of beams, minute (invisible) cracks occur, so that tension exists in the concrete at such sections over a smaller part of the section than is assumed in the elastic theory. The theory is thus approximate and does not suffice to locate exactly the true line of pressures. However, as the full tension (if any) required, is developed at all but a very few sections, it is believed that the pressure line can be located by the usual elastic theory, with a close approximation to the truth. After it has been thus located, if at any section the computed maximum tensile strength of the concrete is exceeded, then it is well to assume that the steel carries all the tension and effect the computation for maximum compression in the concrete and tension in the steel by the proper formulas,* as if the arch was prismatic. This will suffice for the upper part of the arch, but for the lower part, the theory for beams of varying depth is required, the reasoning being similar to that for ascertaining the maximum stress at the face of a dam.† By this theory, if p_0 is the maximum unit compressive stress in the concrete when the arch is treated as a prismatic beam, as above; then the maximum unit stress in the concrete is

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*Hool, in "Reinforced Concrete Construction," vol. III, has given some excellent diagrams to aid in such computations.

$$p_0 \sec^2 \alpha = \frac{p_0}{\cos^2 \alpha}$$

where α is the angle made by the compressed face of the arch (whether upper or lower) with the neutral surface, supposed perpendicular to the Section taken. The angle α is thus the angle between the extrados or intrados (whichever is on the compressed side) and the neutral line. The maximum stress, thus found, is on the side of safety.

As stated above, the usual elastic theory assumes that the whole area of the concrete of any section of the arch is capable of resisting (with the aid of the steel) all the stresses—tensile or compressive— caused by the loading. If the tensile stress of the concrete, thus computed, exceeds its tensile strength at a large number of sections—say, for one-fourth or more of the arch ring—then the resisting area of the concrete at such sections is scarcely more than half that assumed in the theory; the moment of inertia is less than assumed and the neutral line is changed. Evidently, when such conditions exist, the usual elastic theory can give but a rude approximation to the truth, especially if the pressure line, thus found, passes outside the arch ring at one or more sections.

It is difficult to indicate the conditions for which a practical accuracy is obtained and beyond which, the theory in question should not be used; but it is well to give the caution, since there has appeared, of late, a tendency to apply the theory beyond the limit where a reasonable practical accuracy can be attained. This is not good engineering and may lead to greater compressive stresses in the concrete than the computed, with a possibly cracking of the concrete. In such doubtful cases, it seems wiser to use a three-hinged arch.

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†See "Stresses in Masonry Dams," by the writer, in Trans. Am. Soc. C. E., vol. LXIV, p. 222; also App. I, p. 240, on "Wedge-Shaped Beams," of the writer's "Earth Pressure, Retaining Walls and Bins."

Dr. J. A. L. Waddell:* As the writer is primarily responsible for the publication by the Engineers' Society of Western Pennsylvania of Mr. Cochrane's valuable contribution to the literature of re-inforced concrete arch-bridges, it was his intention, jointly with his assistant engineer, Mr. Shortridge Hardesty, to give the paper a thorough discussion, but continued absence from his office and the shortness of time allowed for the receipt of discussions have continued to prevent his so doing; hence he has entrusted the task entirely to Mr. Hardesty, who has done the work in an eminently thorough and satisfactory manner.

The writer heartily endorses all that Mr. Hardesty has said about the value and excellence of Mr. Cochrane's paper, and desires to make in addition a few personal comments of his own.

The author has dwelt with considerable emphasis upon the various approximations to correctness involved in the standard methods of arch computations, viz., the inexact character of the flexure formulae, the uncertain tensile stresses in the concrete, the variation in the live load as to both amount and distribution, and the unknown effects of temperature variation, using these as a plea for the adoption of his approximate, short-cut methods of calculation. The author's reasoning is both sound and sensible; and its tendency is toward the lessening of labor—a desideratum for which, in many lines of computation, the writer has been striving during the last three decades. Anything that saves labor for the computer is a great boon to that uselessly overworked individual. Mr. Cochrane's endeavor in this paper is on similar lines with the writer's long-continued struggle for the substitution of the equivalent-uniform-live-load method of stress computation instead of the tedious and heart-breaking method of concentrated axle-loads.

The contractor who makes plans for re-inforced-concrete arch-bridges and bids on them is prone to forget that such things as arch-shortening and temperature effects exist; and, if his ignoring of them be not found out, he generally will have a good chance of securing the contract. Some engineers in competition

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for work have been known to employ the same reprehensible tactics, and have even built important structures before their deplorably unprofessional methods were discovered. Such practices, of course, should be stopped; but it is very difficult to prevent them so long as county commissioners and other projectors of reinforced-concrete bridges continue to call for competitive plans and estimates in general, instead of choosing some engineer or firm of engineers of wide experience and established reputation to do their designing and supervision of construction. Such competitions are extremely unsatisfactory to the truly experienced and conscientious engineer, who feels pretty certain that if, in his preliminary design he takes proper account of all the governing conditions, his estimate of cost will run so high as to ruin his chance of being retained on the work.

The results of Mr. Cochrane's methods of computation agree very closely with those given in Chapter XXXVII. of the writer's treatise on "Bridge Engineering." This paper and that chapter were evolved simultaneously, but entirely independently, and were not compared until after the said chapter had been printed in page-proof, as was noted at its conclusion.

The writer begs unequivocally to endorse the author's belief. as stated in his Part XIII, concerning the uses for the formulae and diagrams of this paper, and to state that, in his opinion, no computer will make a mistake in adopting Mr. Cochrane's methods for materially reducing labor in reinforced-concrete-arch calculations.

MR. SHORTRIDGE HARDESTY:* Mr. Cochrane's paper on the analysis of stresses in fixed-ended concrete arch ribs appeals to the writer as being a most valuable contribution to our technical literature. In the first place, it makes it possible to determine quickly values of the stresses which, although approximate, can be depended upon in all cases to be fairly close to the correct values, generally within the limits of error in our assumptions; and, in the second place, it contains an extended discussion of the effects of loads in general and of the factors to be considered in determining the best outline of any rib, a clear understanding

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of which points is essential if one is to design arches in an intelligent manner. These features are rarely treated in text-books.

The writer is especially interested in the author's paper, because he himself has made an extensive investigation of this same subject, and has also developed methods for the approximate computation of stresses in arch ribs and piers. These methods are explained in full in Waddell's "Bridge Engineering,'" pages 862 to 880 and 911 to 915. Credit for the derivation of certain of the general features of this method belongs to Messrs. E. A. Slettum and C. W. Yelm. As compared with the author's method, the writer believes that the latter gives slightly more accurate results—at least for ribs of the outlines determined from Fig. 5—while his own perhaps involves somewhat less labor. He considers either method to be entirely satisfactory.

In general, the writer endorses the author's statements and conclusions. He wishes, however, to add a few remarks on certain points.

The writer desires to emphasize strongly the author's statement at the top of page 651, regarding the often-used, but highly improper, plan of computing stresses for only two positions of the live load; also his statement farther down on the same page concerning the necessity of including the arch-shortening effect in connection with every combination of stresses. It might also be added that the effect of temperature must never be overlooked, allowing, as does the author, higher unit stresses when it is taken into account. It appears strange to the writer that these three points so often have been overlooked in design work. He recently had occasion to check the stresses in some existing flat arch ribs, which, according to the stress sheets of the designer, had been figured for the conservative unit stress of 450 lbs. per sq. in. However, the stress analysis was faulty in respect to all three of the points just mentioned; and, when they were duly considered, the unit stresses were found to be about 800 lbs. per sq. in. without taking into account the effect of changes of temperature, and over 1200 lbs. per sq. in. when its effect was included. It is much better practice to consider all effects and permit higher unit stresses, than to use low unit stresses and fail to take into account certain loadings.

The author's remarks on page 644 regarding the practice of making the haunches unduly thick are good. Such an improper thickening of the haunch may increase the arch shortening and temperature stresses 20% or more, which, in a flat arch, will cause a large waste of material. The writer does not, however, favor the use of ribs with haunches quite so thin as those derived from the curves of Fig. 5, as he considers that they are inferior in appearance to ribs having haunches somewhat thicker. He favors a curve similar to that shown for Type $A_{1.5}$; but he would make the increase in thickness at the quarter-point over that at the crown about one-fifth of the total increase from crown to springing. For Type $A_{1.5}$, the value at the quarter-point would be 1.1; for Type $A_{1.75}$, 1.15, and for Type $A_{2.0}$, 1.2. A good formula for this purpose is

$$t_x = t_0 + (t_e - t_0)\,\frac{2x}{l}\left(\frac{\sec\alpha}{\sec\theta}\right)n,$$

the value of n being so chosen that the increase in thickness at the quarter-point is about one-fifth of $t_e - t_0$. The notation employed in this equation is the same as that used in the author's paper, α being the slope of the rib-axis at any point. The value of n may be unity for an arch of high rise, while for a very flat one it may be ten, or even more. It will be found convenient to employ curves plotted by means of this formula, rather than to use the formula itself.

The truly economic law of thickness variation for any rib is affected by the ratio of rise to span length, and by the condition of loading for which the center line of the rib is laid out. For arches of low rise, with the center line coinciding with the dead-load funicular polygon, the author's curves give slightly more economic ribs than does the writer's suggested rule; while for ribs of higher rise, or for ribs laid out for dead load, plus half live load, the reverse is true. The writer usually lays out all ribs for dead load, plus half live load, as this procedure is better suited to the law of thickness-variation which he considers best.

A rather common method of reinforcing arch ribs, mentioned by the author, is that of using the same amount of steel throughout a rib. This often results in a very thick springing, as compared with the crown. The writer considers it better to employ about the same percentages of steel at crown and springing, which gives a greater area of steel at the springing. This arrangement avoids any necessity for the use of very heavy springings, a thickness of from one and six-tenths (1.6) to two (2) times that at the crown being ordinarily sufficient. The area required at the crown is employed for about three-quarters of the rib, the additional steel being needed near each springing only. This procedure results in an economy of both concrete and steel; and it also attains the rapid increase required in the strength of the rib at the springing, pointed out by the author, without adopting the very rapid thickening of the rib. The amount of steel required for most of the length of the rib is, in a flat arch, determined by that required at the crown or at a point quite near thereto; while in an arch of higher rise the critical section will be from one-fifth to two-fifths of the distance from the crown to the springing. In an open-spandrel arch, these critical sections will always be at the load points.

The author mentions (on pages 656 and 704) the fact that there are often found dead-load moments at certain sections of ribs laid out for dead load. For a solid-spandrel arch, these moments, which we may call accidental moments, are caused by the fact that the center line of the rib cannot usually be made to follow exactly the dead-load funicular polygon. The writer has adopted, as an arbitrary allowance for such moments, the value

$$\pm \frac{w\,l^2}{3000}$$

w being the dead load per lineal foot at the section under consideration, and l the span length. In an open-spandrel arch, the accidental moments are due not only to the failure of the center line of the rib to coincide with the dead-load polygon, but also to the fact that the load polygon for concentrated loads is a series of straight lines, while the arch axis is a smooth curve. In an arch of this type, therefore, there will nearly always be positive dead-load moments of considerable magnitude at all load points and at the springing, and somewhat smaller negative dead-load moments at sections midway between the load points. As an arbitrary allowance, the accidental moments at the load points and at the springing can be taken as

$$+\frac{w\,l^2}{1500}\left(\frac{10\,l'}{l}\right)^2, \text{ or } \frac{w\,(l')^2}{15},$$

where l^1 is the distance between load points; and the negative moments at points half-way between the load points can be assumed one-half as large. For a large number of load points, the values found from these formulae may be less than those given by the expression

$$\frac{w\,l^2}{3000}$$

and in this case the latter value should be employed. When figuring maximum negative moments at load points or at the springing, or maximum positive moments at sections half-way between the load points, the accidental moments can be taken as zero.

The foregoing discussion has referred to accidental dead-load moments in ribs laid out for dead loads only. In ribs laid out for dead load, plus one-half live load, the accidental moments under dead-load, plus half live load, can be found in the same manner, *w* becoming the value of the dead load plus half live load per lineal foot at the section being investigated.

The accidental moments are of comparatively small importance in flat arches, in which the arch shortening and temperature stresses are large, and in short-span ribs in general, in which the live-load moments are quite heavy; but, in long-span arches of higher rise, in which the live-load, arch-shortening, and temperature stresses are usually small, they are of greater import, especially in open-spandrel arches with long panels.

The author closes his paper with a list of eight important uses to which his diagrams and formulae are adapted. This list indicates very clearly the great value of the paper to the bridge engineer.

MESSRS. CLIFFORD OLDER, A. W. CONSOER and V. J. FLANAGAN:* The design of an arch is a tedious process, involving time and labor, and any method tending to diminish either of these factors, without increasing the cost of the bridge, or decreasing its efficiency, is a step in the proper direction.

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In evolving accepted methods of arch design, certain preliminary assumptions have always been found necessary. These assumptions, however, have been justified by the results obtained in practice. Whether or not further approximations are justifiable, is a matter which should be given careful study.

It would seem that the best way to check the reliability of the author's formulas, is to test them on arches designed in accordance with accepted practice, and where a distribution of the live load approximating the author's has been used.

In the older designs of the Illinois Highway Department, three positions of the live load for maximum stresses were considered, namely, live load over the center third, over the end third, and over the end two-thirds.

The assumption of loading the end thirds only for maximum negative moment at the crown is a condition not at all likely on highway bridges, and it has therefore, in the practice of the Illinois Highway Department, been neglected. In arches so designed, a close check of the values obtained by the author's approximate formulas could not be expected.

The method of live-load distribution commonly advocated, viz., live load over the half span, and live load over the whole span, does not give the maximum moments and should be discarded. However, the live load over the whole span may influence the substructure design.

Recently a system of live loading, which is practically the same as that recommended on page 683, has been adopted by the Illinois Highway Department. The author's approximate formulas were applied to one of these arches, and the following results were obtained:

TABLES AND COMPARISONS

Span of the arch axis = 71.58 ft.
Rise of the arch axis = 9.42 ft.
Ratio of springing to crown thickness = 2.54.
Weight of dead load at crown = 259 lbs. per ft.

I—ORDINATES OF THE ARCH AXIS

x	$c = \frac{x}{l}$	Value of y	
		Illinois Highway Dept.	$y = \frac{4rl}{1+3r}(c^2+24c^4r)$
1.09	0.0152	0.01	0.006
3.29	0.0460	0.08	0.06
5.53	0.0772	0.17	0.16
7.85	0.1097	0.37	0.33
10.22	0.1428	0.61	0.56
12.69	0.1773	0.96	0.86
15.35	0.2146	1.37	1.28
18.40	0.2570	1.98	1.88
22.21	0.3103	2.87	2.85
30.27	0.4230	6.09	5.99

II—SUMMARY FOR MAXIMUM + MOMENT AT CROWN

Condition of Calculation	Ill. Highway Dept.		Mr. Cochrane		Thrust %	Moment %
	Thrust	Moment	Thrust	Moment		
D. L. . : .	+ 28100	— 2455	+24560	0	87.3	. . . . .
L. L.	+ 5520	+ 2802	+ 5170	+ 3380	93.6	120.7
Temp. . . .	— 4350	+ 6310	— 3710	+ 5700	85.3	90.3
Totals, . .	+ 29270	+ 6657	+ 26020	+ 9080	88.8	136.8

III—SUMMARY FOR MAXIMUM — MOMENT AT CROWN

Condition of Calculation	Ill. Highway Dept.		Mr. Cochrane		Thrust %	Moment %
	Thrust	Moment	Thrust	Moment		
D. L. . . .	+ 28100	— 2455	+ 24560	0	87.3	. . . . .
L. L.	+ 4000	— 1975	+ 4508	—2082	112.7	105.5
Temp. . . .	+ 4350	— 6310	+ 3710	—5700	85.3	90.3
Totals. . .	+ 36450	—10740	+ 32778	— 7782	90.	72.5

IV—SUMMARY FOR MAXIMUM + MOMENT AT SPRINGING

Condition of Calculation	Ill. Highway Dept.		Mr. Cochrane		Thrust %	Moment %
	Thrust	Moment	Thrust	Moment		
D. L.....	+ 3450	— 7685	+ 30720	0	89.	.....
L. L.....	+ 7250	+ 25095	+ 6900	+ 25250	95.2	100.7
Temp....	+ 3550	+ 34660	+ 2950	+ 29200	83.1	84.2
Totals...	+ 45350	+ 52070	+ 40570	+ 54450	89.5	104.5

V—SUMMARY FOR MAXIMUM — MOMENT AT SPRINGING

Condition of Calculation	Ill. Highway Dept.		Mr. Cochrane		Thrust %	Moment %
	Thrust	Moment	Thrust	Moment		
D. L.....	+ 34550	— 7685	+ 30720	0	89.	.....
L. L.....	+ 3450	— 14405	+ 3510	— 13090	101.8	90.8
Temp....	— 3550	— 34660	— 2950	— 29200	83.1	84.2
Totals...	+ 34450	— 56750	+ 31280	— 42290	90.8	74.5

It will be noted that the thrusts are about 10 percent less than those obtained by the exact methods, and the moments vary considerably. This may be due in part to the fact that in the author's formulas the dead-load moment is neglected.

As the formulas proposed are essentially empirical, it would seem the part of wisdom to use with caution the results obtained by them until their reliability has been checked by numerous comparisons with results obtained by exact methods.

Until such comparisons have proved beyond doubt the reliability of these formulas, it is doubtful if they should be used for final designs, even for arches whose axis fulfull the conditions of the author's equations.

However, the methods offered are of inestimable value for determining readily the best form or arch axis and approximate dimensions for final design.

As the author suggests, these methods will also be of much value in making preliminary estimates, and in selecting the most economical span lengths.

Prof. Arvid Reuterdahl:* The reading of the author's paper has afforded me exceptional pleasure. Attempts have been made, heretofore, to bring down from the clouds, the mysteries of arch designing. Most of these attempts have been crude and unscientific and not applicable to general conditions. In this instance, the author has avoided the pitfalls of his predecessors and has made his attack upon the problem in a masterly manner, producing a genuine contribution to the literature, which, in fact, ought to prove epoch-making. He has accomplished for the practice of arch designing what Mohr, Winkler, Menabrea, Fraenkel and Mueller-Breslau have done for the theory of indeterminate structures.

The mechanics of "matter-forms," which resist loads, is the root of engineering. Generally, this root, like our little mathematical friend, "the square root of minus one," is an imaginary quantity. We must imagine the conditions of the problem and then our imagination, backed by experience, must evolve the proper resistive form of the structure. This generally involves quantities of "Love's Labor Lost." Unless something revolutionary in theory is brought out, the writer is tempted to say that we have, for the present at least, enough of theory as far as engineering is concerned. Engineering books and articles are written and—the disgraceful truth must out—published, contributing nothing except a glow of satisfaction to the author and the paper manufacturer. The happy authors vie with one another in engineering mysticism, saturated with the philosophy of the unconscious—unconscious of the fact that, primarily, engineering is an *applied* science. I do not wish to be misunderstood; I am not decrying theory properly expounded and applied, but I am voicing a protest against the unending production of engineering books which differ little from each other. The suffering student of engineering finds all these books equally clear. Clearness, it seems, is not the purpose of these works. The more difficult to understand, the more equations that are amitted, the more profound we must regard the author and his work.

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What engineering needs to-day is a purposive, intelligent compilation of facts ascertainable from the behavior of existing structures. The discovered facts should then be organized into such curves and mathematical expressions as will enable the designer to readily establish that "load-form" of the contemplated structure which will minimize and eventually eliminate the "miss-and-hit" process.

When the chemist mixes two chemical reagents he can positively predict the nature of ensuing reaction. When the engineer places a "matter-form-reagent" in opposition to a "load-reagent" he cannot with certainty predict the reaction. He finds it necessary to try the experiment first—to investigate a tentative design—then he is in a position to announce the nature of the reaction. Nevertheless, there is a fair degree of uniformity in the types of the structure with which he deals. Notwithstanding this, he always is in the experimental stage in so far as the prediction of the worth of an uninvestigated design is concerned. In comparison with the other sciences, engineering is certainly yet in its infancy.

The present contribution is an admirable example of the possibility of emancipating engineering designing from the realm of experimentation.

MR. VICTOR H. COCHRANE:* The writer feels that a considerably larger number of discussions would have been presented if there had been more time available for their preparation; nevertheless, he is pleased to note that a number of important facts relating to arch design have been brought out in the discussion, and that there is a general indorsement of the proposed methods of computation.

Prof. Cain asks how the formulas of Plate I, page 687, were derived. The formulas for the maximum live-load moments and the corresponding thrusts, due to a uniformly distributed load, give the values obtained from the influence line diagram Figs. 7-18 and other similar diagrams not presented herewith. For example, to compute the maximum positive moment at crown for a Type $A_{2.0}$ open spandrel arch having a rise-ratio of 0.10, we get the following values from Fig. 8, by dividing the loaded length into a number of equal divisions (five on each side o the crown), and reading the ordinate at the middle of ea division:

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*Author's closure.

Position of Span Loaded	Moment
From $k = 0.375$ to $k = 0.400$	$0.0030\,l$
" $k = 0.400$ to $k = 0.425$	$0.0090\,l$
" $k = 0.425$ to $k = 0.450$	$0.0162\,l$
" $k = 0.450$ to $k = 0.475$	$0.0255\,l$
" $k = 0.475$ to $k = 0.500$	$0.0370\,l$
Sum =	$0.0907\,l$

Since the length of each division = 0.025 l, the total pos-tive moment due to a uniform load w per unit of length equa

$$0.0907\,l \times 0.025\,l \times 2 \times w = 0.00454\ w\ l^2$$

Other values were computed in like manner and plotted ordinates on cross-section paper with the corresponding values o u_s as abscissas. A series of smooth curves was then drawn fi closely the plotted points, one curve for each value of r for wh computations had been made. These lines had such slight curvatures that each could be closely fitted by a parabola of the gene form

$$(a+bu_s+cu_s^2=C)$$

in which C is the coefficient of wl^2. Substituting three values o C with the corresponding values of u_s gives three simultaneou equations from which values of a, b and c are obtained for a particular value of r. Similarly, values of a, b, and c are found fo other values of r. The next step was to plot these values of a, and c as ordinates with the corresponding values of r as absciss and in a similar manner find expressions for a, b and c in term of r. These being substituted in the original formula there resulted a general expression for the value of the moment in term of u_s and r. In many cases it was necessary, in order to fit all the computed values closely, to alter the constants slightly by cut-and-dry methods. The following table gives the values of the coefficients of maximum positive moments at crown, as compu from the influence lines and as given by Formula 25, Plate I:

Type	$r = 0.10$		$r = 0.20$		$r = 0.30$	
	By Influence lines	By Formula 26	By Influence lines	By Formula 26	By Influence lines	By Formula 26
$A_{1.5}$	0.00510	0.00507	0.00574	0.00579	0.00648	0.00660
$A_{2.}$	0.00454	0.00453	0.00514	0.00519	0.00591	0.00593
$A_{2.25}$	0.00436	0.00432	0.00493	0.00495	0.00570	0.00565
$A_{2.5}$	0.00419	0.00414	0.00469	0.00473	0.00543	0.00541
$A_{2.75}$	0.00400	0.00401	0.00456	0.00457	0.00531	0.00521
$A_{3.}$	0.00385	0.00390	0.00440	0.00443	0.00506	0.00504

It will be seen that the values as given by the formula differ from the computed values by less than 2%. These results are typical of the other formulas. It would seem, therefore, that the formulas are not "essentially empirical," as stated in the discussion by Messrs. Older, Consoer and Flanagan. The values obtained from them are, practically speaking, exact for arches having the shape of axis as determined by equation 12 or equation 15, and having thickness, as shown in Fig. 5, for rise-ratios up to 0.40, or perhaps more. For arches having axis of different shape or following different laws of variation in thickness, the formulas give more or less approximate results, but it will be found that in all ordinary cases the thrusts and moments as determined by the formulas will be close enough to the true values to enable dimensions to be chosen for the arch which will require but little, if any, alterations after an analysis is made in accordance with exact methods.

The writer regrets that he must give a negative reply to Prof. Cain's inquiry as to whether he attempted to derive equations for the curves, Figs. 7 and 8.

Mr. Hardesty says that if the amount of steel used is considerably increased at the ends of the arch, the value of u_a ordinarily varies from 1.6 to 2.0. The writer's experience is that for arches not having such especially heavy reinforcement near the ends, u_a varies from about 1.75 to 2.25, the value 2.0 being found about right for arches differing greatly with respect to span, rise and loadings. If further experience demonstrates that a range of values of u_a of from 1.5 to 2.5 will be sufficient for all cases, the formulas may be considerably simplified, inasmuch as the variations in the constants with respect to u_s may be represented by straight lines. The variations with respect to r may also be represented by straight lines with but little error, thus still further simplifying the formulas. It is not claimed, therefore, that the formulas given on Plate 1 are the best that can be devised, for they can doubtless be improved. In practice it is somewhat tedious to make the substitutions in the formulas and, instead of using them directly, it would be well for the designer to prepare diagrams for three or more values of u_s with the values of r as abscissas and the values of the moments, thrusts, etc., as ordinates. Having such diagrams at hand, the desired values may be read off at a glance.

In many cases, especially when the intrados curve is approximately elliptical, there is a local thickening, or filleting, of the rib at the springing. This abrupt increase in thickness at the springing should be disregarded in determining the value of u_s and in computing the stresses at springing. Of course, such thickening of the arch lowers the stresses at the springing, but at a short distance away from the springing the stresses will be about the same as computed for the springing section, if the filleting is disregarded.

The thickness-variation diagrams of Fig. 5 are criticized by Mr. Hardesty on the ground that such arches are not as sightly as arches somewhat thicker in the haunches. The writer does not altogether agree with this view, although he recognizes that for arches of larger rise-ratio, it may be desirable to use thicker haunches. In order that the reader may judge for himself as to the appearance of arches corresponding in thickness-variation to the diagram of Fig. 5, the following cases may be mentioned. In Hool's *Reinforced Concrete Construction,* Vol. III, page 12, Fig. 10-B, is a cut of the Murray Avenue Bridge in Pittsburgh. The arch corresponds almost exactly to Type $A_{1.75}$ Fig. 5. On page 612 of the same book there are shown several views of Prof. Melan's Chauderon-Montbenon Bridge (Example 4, page 705, above). This arch corresponds to $A_{2.5}$. Fig. 23 is a view of the Lawrence Bridge (Example 3, page 695), the arches being Type $A_{2.25}$. In the case of the Ludlow Avenue Bridge in Cincinnati (See pages 12, 319, 320, Hool, Vol. III) the thin portion of the arch seems to have been continued to a

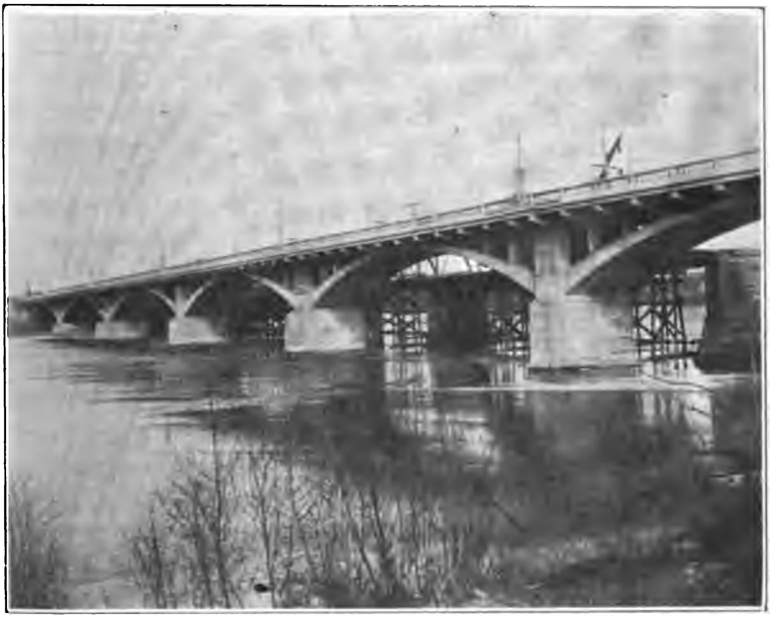

Fig. 23. Lawrence Bridge.

point much closer to the springing than would be the case in an arch laid out according to the diagrams of Fig. 5.

The writer agrees with Prof. Cain and Mr. Hardesty that for arches of large rise-ratio and carrying comparatively heavy live loads, the neutral axis should be laid out for dead load plus one-half live load. In such case the combined live and dead load moments are equal to half the arithmetical sum of the positive and negative live-load moments as determined by the formulas, as stated on page 686, and as clearly shown by Prof. Cain. This rule applies only to arches for which the same uniformly distributed live load is used for all sections, which is usually the case only for arches of long span, since for short-span arches the effect of the heavy concentrated loads now generally and properly specified, may be more severe than the uniform load for some sections of the arch, and less severe for others.

Equations 170 and 173, pages 865, 866, Waddell's *"Bridge Engineering,"* referred to by Mr. Hardesty, used for determining the center line of arch-rib, and which are credited to Messrs.

A. E. Slettum and C. W. Yelm, are the same as equations 7 and 8, page 658, above when reduced to the same notation. Equations 76 and 77, page 93 of Steinman's translation of Melan's *"Plain and Reinforced Concrete Arches,"* also reduce to the same expression. All these formulas, while developed independently, are based upon the same simple assumption, that the increase in load from crown to springing varies as the square of the distance from the crown. Now for filled spandrel arches it is more nearly correct to assume that the increase in load varies as the cube of the distances from the crown, as was done in deriving equations 10 and 11, page 659.

Prof. Cain asks whether in the case of flat arches the segment of a circle may not be used economically for the arch axis? The writer's experience has been that for open-spandrel arches having a rise-ratio of one-eighth or less, the segment of a circle so nearly coincides with the dead-load equilibrium polygon that it may be used for the arch axis. For filled-spandrel arches the segment of a circle is not economical, even for flat arches.

It may be well to state here that, while the formulas and diagrams herewith apply only to symmetrical arch ribs, it is not necessary that the dead load be symmetrical. A case frequently coming up is that of a filled-spandrel arch carrying a roadway on a grade, so that the dead load is greater at one end of the span than at the other. The arch-rib may be made symmetrical, both for the sake of appearance and to facilitate its design. For such an arch, if the axis is laid out according to equation 15, the dead-load moment and horizontal thrust at crown and the dead-load moments at the springings may be quickly found with the aid of the influence lines. The points at crown and springings through which the dead-load equilibrium polygon must pass are then known, and the equilibrium polygon may be constructed and the moments and thrusts at any point determined by scaling. It is, perhaps, needless to point out that influence lines for the live-load thrusts and moments at any section may be quickly constructed with the aid of the influence lines given for the crown section.

The formulas of Plate I for average stresses are more or less approximate, the exact values being different for open spandrel and filled-spandrel arches. Prof. Cain gives a clear demonstration of the fact that the correct method of computing the average stress requires that the span, rather than the axis, be divided into equal parts. The computation of the average stresses for all the different loadings is long and tedious, and the writer believes that the formulas of Plate I are sufficiently accurate for the purpose if the arch thicknesses conform approximately to the diagrams of Fig. 5, especially in view of the uncertainty regarding the coefficient of elasticity of the concrete.

Prof. Cain's remarks concerning the behavior of an arch while on the forms are very interesting and instructive. The writer agrees in his conclusion that it is more logical to assume a fall in temperature of 60° and a rise of 20° in case the arch is poured at mean temperature. The combined effect of the arch-shortening and a temperature drop of 60° is very severe, and there must be minimum values of the rise-ration beyond which it is impossible to design an arch without exceeding the allowable working stresses.

The tabulation of stresses given by Messrs. Older, Consoer and Flanagan for the arch designed by the Illinois Highway Department is interesting. The dead-load thrusts, as given by formulas 17 and 39, Plate I, are considerably smaller than the actual dead-load thrusts. However, it is not intended that these formulas should be used except for approximate preliminary calculations, as indicated in the first column of Plate I. The proper procedure is to lay out the dead-load equilibrium polygon passing through the centers of crown and springing and then scale the thrusts from the force polygon. In a letter to the writer Mr. Older gives the following dead loads, the half-span being divided into ten sections, each 3.5 ft. long:

Section No.	Distance from Crown	Dead Load
1	1.75	914
2	5.25	993
3	8.75	1104
4	12.25	1305
5	15.75	1512
6	19.25	1814
7	22.75	2248
8	26.25	2762
9	29.75	3450
10	33.25	4320

Using the above loads, the force polygon gives:

Thrust at crown $= 28600$
Thrust at springing $= 35100$

These thrusts being substituted for those obtained from formulas 17 and 39, it will be seen that the total thrusts agree very well with those computed by the exact method.

The axis of this arch lies somewhat below the dead-load equilibrium polygon through crown and springing, and, consequently, the dead-load moments at crown and springing are negative. Following the methods of design proposed in this paper, the proper procedure would be to alter the shape of the arch axis to fit the dead-load polygon, or, if for any reason this is undesirable, the dead-load moments should be determined by the exact method. Eliminating the dead-load moments from comparison, the sum of the live load and temperature moments by the exact and approximate methods are as follows:

	By Exact Method	By Approximate Method	%
Max. + Mom. at crown...........	9112	9080	99.6
Max. — Mom. at crown...........	8285	7782	93.9
Max. + Mom. at springing........	59755	54450	91.1
Max. — Mom. at springing........	42290	42290	86.2

In conclusion, the writer may be permitted to state his belief that the methods of design herein advocated may be amplified and improved by selecting another set of typical arches somewhat thicker in the haunches, and computing coefficients both for these typical arches and those of Fig. 5 for two or three values of ρ for both open and filled spandrel ribs, using values of $u_t =$ 1.5, 2.0 and 2.5. Now that the way has been marked out the labor involved would not be formidable, since the values computed vary so regularly that intermediate values can be readily obtained by plotting the computed values and drawing smooth curves through them. If this scheme should be carried out, we should then have what would amount to a pre-design of practically all ordinary symmetrical arches.

The writer desires to express his thanks to those participating in the discussion.

The Engineers' Society

of

Western Pennsylvania

INCORPORATED 1880

ABSTRACT OF MINUTES

Volume 32

FEBRUARY 1916—JANUARY 1917

ANNUAL MEETING

The Thirty-sixth Annual Meeting of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Building, Pittsburgh, Tuesday, January 18, 1916, at 8:30 P. M., President A. Stucki presiding, 68 members and visitors being present.

The minutes of the last annual meeting, held January 19, 1915, were read and approved.

The annual report of the Board of Direction, which included the reports of the Standing and Special Committees, the Sections and the Treasurer, was read as follows:

REPORT OF THE BOARD OF DIRECTION

The Board of Direction of the Society held ten regular and two special meetings during the past year, at which the routine of business of the Society was transacted.

During the year there were held nine regular monthly meetings, one special and the annual meeting of the Society. Total attendance was 1044, the average being 95. The maximum attendance was 156, the minimum 36 and the average number participating in the discussion of papers was 8.

At the close of the year the membership of the Society was as follows:

Honorary Members	5
Members	979
Associate Members	28
Associates	25
Juniors	93
Student Juniors	32
Total	1162

This is the largest membership in the history of the Society. During the year there were:

Resignations	61
Removed by death	12
Dropped	1
Total	74
Accessions	84

The net increase in membership during the year is 15.

REPORT OF HOUSE COMMITTEE

To the Board of Direction, Engineers' Society of Western Pennsylvania:

On behalf of the House Committee, I have the following report to present:

The equipment of the Library has been added to by the purchase of two chess tables.

The equipment of the office has been added to by the purchase of two new typewriters, a desk and chair, a telephone stand and stool.

It is gratifying to note that the Society Rooms are being used more and more by our members. Our chess players are coming in quite regularly during the noon hour, and there is always opportunity for a game.

During the year the auditorium has been used 35 occasions, 24 times for Society meetings, and 11 times for other organizations.

The Society Rooms have been open every Saturday night throughout the year.

Respectfully submitted,

E. H. Haslam, *Chairman.*

REPORT OF PUBLICATION COMMITTEE

To the Board of Direction, Engineers' Society of Western Pennsylvania:

The activities of the Publication Committee during the past year have been directed along the same lines as in previous years in securing papers of interest and value to the various industries of this section, and also in securing capable men to present them.

The character of the papers is well indicated by the increasing number of abstracts which are printed in various technical journals with favorable comment, and the volume of discussion brought out.

Quite a few members have co-operated with the Committee by suggesting both subjects and speakers, and the Secretary has continued his usual good work along these lines, so that little has remained for the committee to do except in an advisory capacity.

It would be well to have still more members take an interest in this part of the Society's work by suggesting topics to the Committee, so that the best possible material be secured for our Proceedings.

Respectfully submitted,

Frederic Crabtree, *Chairman.*

REPORT OF ENTERTAINMENT COMMITTEE

To the Board of Direction, Engineers' Society of Western Pennsylvania:

During the past year your Committee arranged the following Inspection Trips and Entertainments:

INSPECTION TRIPS

June 16—To Pennsylvania Rubber Co. works at Jeannette, Pa. Attendance, 95.

July 10—To the new building of the Logan-Gregg Hardware Co. to inspect the structural steel work done by the Jones & Laughlin Steel Co. Attendance, 75.

July 17—To the Magnolia Cut-Off Improvement on the east end of the Cumberland Division of the Baltimore & Ohio Railroad. Attendance, 200.

SMOKERS

April 6—Hotel Schenley. Talk by Lieutenant Logan Cressap, United States Navy, on "The Weapons of Naval Warfare."

October 15—Fort Pitt Hotel. Westinghouse Club Quartette; Monologue by C. S. Carter; Sketch by R. S. Healy and J. H. Bell; Monologue by W. H. Dithrich. Attendance, 158.

RECEPTIONS

November 18—Rittenhouse. Reception and Dance. Attendance, 105.

The banquet was held at the Hotel Schenley. Attendance, 810.

Arrangements have been practically completed for the Annual Banquet for the year 1916, which will be held Monday evening, February 14, at Memorial Hall. The speakers will be

Samuel Insull, President, Commonwealth Edison Co., Chicago

Alba B. Johnson, President, Baldwin Locomotive Works, Philadelphia

Wilbur D. Nesbit, Author and Raconteur, Chicago

Respectfully submitted,

GEORGE H. NEILSON, *Chairman.*

REPORT OF FINANCE COMMITTEE

To the Board of Direction, Engineers' Society of Western Pennsylvania:

During 1915 the Finance Committee has attended to the following work:

1. It audited the monthly financial statements of the Secretary and approved same each month to the Board.

2. It investigated the present status of the various companies whose bonds are now owned by the Society, and reported in detail upon these to the Board, recommending that the bonds owned by the Society be retained.

3. It investigated bonds for the investment of money in the permanent fund of the Society, and recommended the purchase of six bonds, as follows:

Two of the Pennsylvania Railroad Co.
Two of the Union Steel Co.
Two of the Jamison Coal & Coke Co.

These were eventually purchased.

4. It has considered plans to improve the present method of operating the financial department of the Society, so as to facilitate the work of the Secretary in his handling of the Society business. The purpose of the plan is to adapt a monthly expenditure which varies somewhat from month to month to a monthly income, which also varies through a considerable range. After plans for this have been approved by the Board, they will be submitted to the Society for final action.

Respectfully submitted,
W. E. SNYDER, *Chairman.*

REPORT OF MEMBERSHIP COMMITTEE

To the Board of Direction, Engineers' Society of Western Pennsylvania:

The Membership Committee desires to report the following accessions to membership in the Society during the past year:

Members	56
Associate Members	11
Associates	1
Juniors	9
Student Juniors	7
Total	84

The Junior membership of the Society now numbers 93, and it is believed that this grade of membership should be increased in order to extend our field of usefulness. It is hoped that during the coming year more of the advanced students in the engineering schools of the city will avail themselves of the privileges of the Student Junior grade of membership, and it is desired to bring this matter particularly to the heads of the Engineering Departments of the local engineering schools, as such membership in the Society will prove of great benefit to the engineering students.

Respectfully submitted,
SAMUEL E. DUFF, *Chairman.*

REPORT OF TREASURER

To the Board of Direction, Engineers' Society of Western Pennsylvania:

Before reading the report, will you indulge me a moment? I am not at all aware that the constitution or the charter of the Society gives it any power to preserve relics, but such seems to have been the disposition from year to year, for I may regard myself in the nature of a relic. So, annually I appear for the delivering of the report and I am reminded by a note that this is my thirty-fifth annual report. [Applause.] I think that I can say safely that the first report harks back to a time when some of you had not seen the light. [Laughter.]

INVESTMENTS

Building Fund

One $1000 Butler Water Company 5 percent bond, No. 9; matures September 2, 1931	$1025.00

Permanent Fund

Two $1000 Connellsville Water Co. 5 percent bonds, Nos. 317-318, maturing October 1, 1930	2020.00
Two $1000 Portsmouth, Berkley & Suffolk Water Co. 5 percent bonds, Nos. 465-466, maturing November 1, 1944	2000.00
Two $1000 Jamison Coal & Coke Co. 5 percent bonds, Nos. 1502-3, maturing November 1, 1931	2000.00
Two $1000 Union Steel Co. 5 percent bonds, Nos. 36642-43, maturing December 1, 1952	2090.00
Two $1000 Pennsylvania Railroad Co. 4½ percent bonds, Nos. 27320-21, maturing August 1, 1960	2070.00
Three $1000 Jones & Laughlin Steel Co. 5 percent bonds, Nos. 3020-3022, maturing May 1, 1931	2997.92
Total fourteen bonds	$14 202.92

RECEIPTS	
Dues 1916	$ 43.00
1915	9592.31
1914	296.73
1913	59.00
1912	45.00
1911	5.00
1910	10.00
1909	15.00
Entrance Fees	730.00
Advertising	1986.54
Proceedings	1194.46
Rent of Auditorium	173.75
Banquet Receipts	3124.00
Smoker Receipts	245.00
Reception Receipts	154.50
Inspection Trip Receipts	2.33
Interest	799.44
Society Pins	42.50
Miscellaneous	40.94
	$18 559.50

EXPENDITURES	
Administration	$ 5243.32
Entertainment	3146.12
House	3173.29
Library	36.85
General Society	1096.41
Mechanical Section	197.88
Structural Section	379.32
Metallurgical and Mining Section	216.09
Committee on Engineering Education	91.11
Membership Committee	329.43
Proceedings	3846.26
Advertising	276.23
Miscellaneous	251.81
	$18 284.12

	December 31, 1914	December 31, 1915
Permanent Fund—Bonds	$8042.92	$14 202.92
Permanent Fund—Cash	5611.37	423.34
Building Fund—Cash	586.37	586.37
General Fund—Cash	912.66	143.04
	$15 153.32	
Increase in Assets for 1915 over 1914	202.35	
	$15 355.67	$15 355.67

Respectfully submitted,

ALBERT E. FROST, *Chairman.*

REPORT OF MECHANICAL SECTION

To the Board of Direction, Engineers' Society of Western Pennsylvania:

Four regular meetings of the Mechanical Section of the Society were held in 1915, with an average attendance of 102. The maximum attendance was 160, at the February meeting, and the minimum 56, at the June meeting. The average number participating in the discussion of papers was 10.

The papers presented were as follows:

February Meeting: "Tests on a New Type of Chain Grate Stoker and New Methods of Baffling Stirling Boilers," by John A. Hunter, Steam Engineer, American Sheet & Tin Plate Co.

April Meeting: "The Electric Furnace for Reheating, Heat-Treating and Annealing," by T. F. Bailey, President, The Electric Furnace Company of America.

June Meeting: "Pipe Couplings," by R. S. Lord, Vice President, Hope Engineering & Supply Co.

October Meeting: "Gas Welding and Cutting—A Symposium,"—"Use in Welding Heavy Parts," by C. K. Bryce, Oxweld Acetylene Co.; "Use in Steel Foundries," by J. B. Henry, General Superintendent, Union Steel Casting Co.; "Use in Steel Mills," by A. F. Mitchell, Assistant to Superintendent, Armor Plate Dept., Carnegie Steel Co.

These papers were selected with the idea of presenting subjects of particular interest to the mechanical engineers in the Pittsburgh District. The adoption of this policy, which has been recommended some time ago by the Board of Direction, has been fully justified during the past five years by the experience of the Mechanical Section.

Respectfully submitted,
John A. McCulloch, *Chairman.*

REPORT OF METALLURGICAL AND MINING SECTION

To the Board of Direction, Engineers' Society of Western Pennsylvania:

Four regular meetings of the Metallurgical and Mining Section of the Society were held in 1915, with an average attendance of 79, the maximum attendance being 171, at the January meeting, and the minimum 45, at the May meeting. The average number participating in the discussion of papers was 7.

The papers presented were as follows:

January Meeting: "The Trend of Modern Blast Furnace Construction," by A. E. Maccoun, Supt., Edgar Thomson Works, Carnegie Steel Company.

April Meeting: "Oil Concentration of Ores," by Howard W. DuBois, Consulting Engineer, Philadelphia.

May Meeting: "The Thermal Efficiency of the Electric Furnace," by Woolsey McA. Johnson, Consulting Metallurgical Engineer, New York City.

September Meeting: "Design of Bituminous Mining Plants," by W. A. Weldin, Proposal Engineer, Pittsburgh Coal Washer Co.

Respectfully submitted,
W. E. Fohl, *Chairman.*

REPORT OF STRUCTURAL SECTION

To the Board of Direction, Engineers' Society of Western Pennsylvania:

I beg to submit the following report of the work done by the Structural Section during the year 1915:

Five regular meetings of the Section were held during the year. The average attendance at these meetings was 85; the maximum being 137, and the minimum 47.

An average of 12 participated in the discussions of the several papers presented. The papers read during the year were as follows:

January Meeting: "The Emergency Dams of the Panama Canal," by O. E. Hovey, Asst. Chief Engineer, American Bridge Co., New York.

March Meeting: "Protection of Metal Structures," by Frederic H. Fay, Consulting Engineer, Fay, Spofford & Thorndike, Boston.

May Meeting: "Local Sands and Gravels as Aggregates in Concrete," by F. M. McCullough, Asst. Professor of Materials, Carnegie Institute of Technology.

September Meeting: "The Four-Track Subway Tunnel Under the Harlem River," by Olaf Hoff, Consulting Engineer, New York; and "Details and Fabrication of the Harlem River Tubes," by Thomas Duckworth, Engineer, Brooklyn Plant, American Bridge Co.

November Meeting: "Highway Bridge Floors," by Charles M. Spofford, Hayward Professor of Civil Engineering, Massachusetts Institute of Technology; also of Fay, Spofford & Thorndike, Consulting Engineers, Boston, Mass.

Respectfully submitted,

HORACE R. THAYER, *Vice Chairman.*

REPORT OF COMMITTEE ON ENGINEERING EDUCATION

To the Board of Direction, Engineers' Society of Western Pennsylvania:

On behalf of the Committee on Engineering Education, I have the following report to present of the work accomplished during the past three years by this Committee:

For the season 1913-14 the following institutions were represented, sending in solutions to problems in the different branches of engineering as shown below:

	Civil	*Electrical*	*Mechanical*	*Total*
Ohio State University	20	22	16	58
Pennsylvania State College	52	20	....	72
Case School of Applied Science	8	10	....	18
Tufts College	10	4	4	18
Carnegie Institute of Technology	12	12	15	39
Cooper Union	28	....	....	28
Georgia School of Technology	....	34	....	34
Total	130	102	35	267

For the season 1914-15 the following institutions were represented, sending in solutions to problems in the different branches of engineering as shown below:

	Civil	*Electrical*	*Mechanical*	*Total*
Carnegie Institute of Technology	9	7	21	37
Cooper Union	10	....	....	10
Georgia School of Technology	....	3	....	3
Tufts College	6	3	2	11
University of Maine	2	....	....	2
Ohio State University	1	....	....	1
Total	28	13	23	64

For the season 1915-16 the following institutions sent in for copies of problems in the different branches of engineering as shown below:

	Civil	*Electrical*	*Mechanical*	*Metallurgical*	*Hydr. and Sanitary*	*Total*
Carnegie Institute of Technology	15	18	45	5	15	98
Georgia School of Technology	....	35	....	....	....	35
Pennsylvania State College	30	....	....	....	30	60
Rose Polytechnic Institute	2	....	....	....	2	4
University of Maine	1	....	....	....	....	1
University of Michigan	3	....	....	....	....	3
University of Illinois	....	....	....	2	....	2
University of South Dakota	1	....	....	....	....	1
Total	52	53	45	7	47	204

Ohio State University, Tufts College and University of Kansas are planning to enter the competition, but have not sent in the number of students who intend to compete.

In 1913-14 the following awards were made in the different branches:

	Civil	*Mechanical*	*Electrical*
First Award............	**Tufts College**	**Tufts College**	**Georgia School of Technology**
Second Award	**Pennsylvania State College**	**Carnegie Institute of Technology**	**Georgia School of Technology**
Third Award	**Carnegie Institute of Technology**	**Carnegie Institute of Technology**	**Pennsylvania State College**
Honorable Mention	**Pennsylvania State College**	**Carnegie Institute of Technology**	**Georgia School of Technology**
Honorable Mention	**Pennsylvania State College**	**Carnegie Institute of Technology**	**Georgia School of Technology**
Honorable Mention	**Tufts College**	**Carnegie Institute of Technology**	**Carnegie Institute of Technology**
Honorable Mention	**Cooper Union**	**Carnegie Institute of Technology**	
Honorable Mention	**Cooper Union**		

making a total of 21 awards in 1913-14, comprising a first, second and third award in each of the three branches and five honorable mentions in Civil Engineering, four in Mechanical Engineering and three in Electrical Engineering.

In 1914-15 the following awards were made:

	Civil	*Mechanical*	*Electrical*
First Award............	**University of Maine**	**Carnegie Institute of Technology**	**Carnegie Institute of Technology**
Second Award	**Cooper Union**	**Carnegie Institute of Technology**	**Carnegie Institute of Technology**
Third Award	**Carnegie Institute of Technology**	**Carnegie Institute of Technology**	**Carnegie Institute of Technology**
Honorable Mention	**University of Maine**	**Tufts College**	**Georgia School of Technology**
Honorable Mention	**Carnegie Institute of Technology**	**Tufts College**	**Tufts College**
Honorable Mention	**Tufts College**		

making a total of 16 awards in 1914-15, comprising a first, second and third award in each of the three branches, three honorable mentions in Civil Engineering, two in Electrical and two in Mechanical.

In each of the above-mentioned cases the student receiving the award or honorable mention was presented with a suitably engrossed certificate.

While the plan of the competition has received the general approval of the faculties of the various colleges competing, there have been some few criticisms from members of these faculties which will be considered at the next meeting of our committee, with a view to preventing any misunderstanding as to its object.

Respectfully submitted,

F. N. SPELLER, *Chairman.*

REPORT OF COMMITTEE ON 100 FOOT STANDARD

To the Board of Direction, Engineers' Society of Western Pennsylvania:

The Committee appointed to install a Bench Standard in the new City-County Building begs leave to submit the following progress report:

This project has received the sanction of the Building Committee of the City-County Building, and a room 13 ft. by 108 ft. has been set apart in the basement, for the installation of a 100 ft. long bar standard accurately graduated at the 1, 2, 3, 4, 5, 6, 8, 10, 25, 50, 75 and 100 ft. points. The Committee has been in consultation with Mr. Sidney L. Rousch, City Architect, regarding the features of lighting, ventilation, etc. The Committee has consulted with Director S. W. Stratton and Prof. L. A. Fischer, of U. S. Bureau of Standards; Mr. U. C. Waye, of Interior Department of Canada, and with the authorities in charge of the Chicago installation. Personal inspection of the Chicago Standard has been made by our Secretary.

The Committee is keeping in touch with the construction progress on the City-County Building, and hopes to complete a satisfactory installation as rapidly as circumstances will allow.

Yours very truly,

LOUIS P. BLUM, *Chairman.*

REPORT ON BUILDING CODE

As probably most of you gentlemen know, the City of Pittsburgh has been trying for a number of years to get together a new building code. Last summer the matter took definite form in a request from the City Council to various civic bodies in Pittsburgh for each of them to appoint a member to a committee for the purpose of drafting a new code. Our Society was requested to appoint such a member, and Mr. J. A. Ferguson was so appointed. Shortly afterwards Mr. Ferguson resigned to take up other work in connection with the code, and our President, Mr. Stucki, appointed me to be his successor.

This Committee and the interests represented are as follows:

Robert Garland, Chairman.

W. I. English S. S. Woodburn John M. Goehring	Representing	City Council.
Sidney F. Heckert,	"	Chamber of Commerce.
Richard Hooker,	"	Pittsburgh Chapter of American Institute of Architects.
J. C. Wilson,	"	Builders' Exchange.
F. S. Guthrie,	"	Civic Club.
R. J. Trimble,	"	Board of Fire Underwriters.
George H. Schwan,	"	Housing Conference.
W. W. Mearkle,	"	Real Estate Exchange.
C. H. Chance,	"	Real Estate Board.
John Dimling,	"	Allied Board of Trade.
J. J. McKee,	"	Iron City Trades Council.
J. H. Duty,	"	Building Trades Council.
G. H. Danforth,	"	Engineers' Society of Western Pennsylvania.

A committee of the size of the above would be difficult to get together and could not work effectively, so there was appointed an executive committee, which is really a subsidiary to the main committee and which does all the preliminary work, and is composed of:

Robert Garland, Ex officio
Sidney F. Heckert, Chairman

J. C. Wilson
Richard Hooker
George H. Schwan
R. J. Trimble
F. S. Guthrie
C. H. Chance
G. H. Danforth
Members

The Executive Committee has held five meetings, namely, on September 20, November 3, November 19, December 8 and December 9.

There has also been appointed in this Society by President Stucki, to work in conjunction with the City Committee, a Building Code Committee, consisting of:

Samuel E. Duff, Chairman
Hermann Laub
George H. Barbour
J. F. Kuntz
Arthur V. Spinosa

This Committee of the Society has not as yet been called upon for anything, for the reason that the General Committee has not reached those sections of the code which will particularly interest the members of the Society—that is, those actions of the code that govern the use of materials

I feel that there has to be very great care exercised in the compilation of this code. It is not simply a matter of specifying something that will make a safe building, but the interests of the owner and the interests of the tenant have also to be considered. They demand something cheap, and to strike the balance between that which is cheap and that which is at the same time safe is going to be a very, very difficult problem.

Respectfully submitted,

GEORGE H. DANFORTH.

REPORT OF TELLERS

To the Members of the Engineers' Society of Western Pennsylvania:

The Tellers publicly canvassed the ballots cast in the annual election of the Engineers' Society of Western Pennsylvania, with the following results:

For President:	Samuel E. Duff	244
For Vice President:	W. E. Snyder	244
For Treasurer:	A. E. Frost	244
For Director:	Henry D. James	245
For Director:	William E. Mott	244
Scattering		2
Total number of ballots cast		248

Respectfully submitted,
JOHN A. FERGUSON,
B. F. GROAT,
E. J. DECKMAN,
Tellers.

These gentlemen were thereupon declared elected.

PRESIDENT STUCKI: Gentlemen, you have heard the report of the election, complimentary indeed. I just want to point out that our Society has another year to its credit. I say credit, because it is a credit—professionally, financially and socially. We have gone through the tail-end of a depression, longer than any I have ever experienced, and that is hard on the engineers and hard on the Society; but in spite of that we held our own. Our papers are up to date and, as a rule, they are considered authoritative. The social side, sometimes neglected in the past, has been considerably revived to the satisfaction of all concerned, and I think that we have reason to rejoice.

If you would ask me who is responsible for such good results, I would say that you all are. Our trio—Duff, Neilson and Hiles—spell success in themselves; and there are a great many just like them. The chairman and the members of the various committees have worked hard, with zeal and enthusiasm and excellent results have been accomplished. The vice presidents and the past presidents have attended our meetings, directors' meetings and the general and sectional meetings very faithfully; and many directors have come here in spite of the fact that they were very badly needed somewhere else. I want to take this occasion to express my deep appreciation to the officers of the Society, to every one of them, for their hearty co-operation and support. And I also want to thank all our members for the great interest taken in the Society.

It is about thirty-five years ago since a few enthusiastic engineers started this Society. Now we have nearly twelve hundred members. The time has passed when a small body of men, or any one man, can dictate the policies of this, our large organization. You all will have to take a hand; every engineer in this district should take a hand in it. Our aim is to centralize the interests of all of the engineers in this community; to provide a home and to make everyone welcome, and we sincerely hope that everyone in our district will join us and help carry on the work which is so nicely under way.

It gives me now great pleasure indeed to present to you the new President. He is a man who needs no introduction, a man who is big in more ways than one. I will ask Mr. Snyder and Mr. Hoerr, our Vice Presidents, to escort our new President to the platform.

President Samuel E. Duff: Gentlemen, I know you believe that I appreciate the honor you have given me. I yield to no man in my appreciation of the greatness and influence of this Society and accept the honor of presiding over it with a deep sense of the duty as well as the privilege you have placed upon me.

No further business coming before the Society, the President's retiring address on "Some Details Often Neglected by Engineers" was presented by A. Stucki, Consulting Engineer, Pittsburgh.

The ensuing discussion was participated in by: F. W. H. Clay, Patent Attorney, Pittsburgh; Samuel E. Duff, Consulting Engineer, Pittsburgh; E. W. Hankele, Engr., Edgar Thomson Works, Carnegie Steel Co.; John A. Ferguson, Secy-Engr., Building Code Commission, Pittsburgh; Henry D. James, Asst. to Mgr. Engineering, Westinghouse Elec. & Mfg. Co.; Louis P. Blum, Engr., W. G. Wilkens Co., Pittsburgh; W. E. Snyder, Mech. Engr., American Steel & Wire Co., Pittsburgh; D. W. Howe, Local Mgr., Jos. Dixon Crucible Co., Pittsburgh; and the author.

On motion, the annual meeting adjourned at 10:45 P. M.

Elmer K. Hiles, *Secretary*.

STRUCTURAL SECTION

The annual meeting of the Structural Section was held in the Society Rooms, Oliver Bldg., Pittsburgh, Tuesday, January 4, 1916, at 8:20 P. M., Vice Chairman H. R. Thayer presiding, 70 members and visitors being present.

The minutes of the last Annual Meeting were read and approved.

Mr. George H. Danforth, on behalf of the Nominating Committee, reported the nomination of the following officers for the ensuing year:

Horace R. Thayer, Chairman
George W. Nichols, Vice Chairman
J. F. Kuntz }
E. W. Pittman } Directors
A. W. Neeld }

No further nominations being made, the Secretary was instructed to cast a unanimous ballot for the members named, who were thereupon declared elected.

There being no further business, the meeting adjourned at 8:28 P. M.

The regular bi-monthly meeting of the Structural Section of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Bldg., Tuesday evening, January 4, 1916, at 8:30 P. M., Chairman H. R. Thayer, presiding, 70 members and visitors being present.

The minutes of the last regular meeting, held November 9, were read and approved.

No further business coming before the Section, the paper of the evening on "The Relation Between Engineers and Contractors" was read by Mr. James W. Rollins, President, Holbrook, Cabot & Rollins Corp., Contractors and Engineers, Boston.

Discussion by correspondence was presented by: J. G. Chalfant, County Engr., Allegheny County, Pittsburgh; W. C. Hawley, Chf. Engr., Pennsylvania Water Co., Wilkinsburg, Pa.; Henry S. Prichard, American Bridge Co., Pittsburgh; Samuel E. Duff, Cons. Engr., Empire Bldg., Pittsburgh; Thos. P. Roberts, Civil Engr., U. S. Engineer Office, Pittsburgh.

The ensuing discussion was participated in by: F. R. Dravo, President, Dravo Contracting Co.; G. W. Snyder, Prin. Asst. Engr., Pennsylvania R. R.; L. J. Affelder, Asst. Div. Contr. Engr., American Bridge Co.; C. L. McKenzie, President, Pittsburgh Construction Co.; and the author.

The meeting adjourned at 10:40 P. M.

ELMER K. HILES, *Secretary.*

METALLURGICAL AND MINING SECTION

The annual meeting of the Metallurgical and Mining Section of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Bldg., January 25, 1916, at 8:20 P. M., Acting Chairman A. L. Hoerr presiding, 75 members and visitors being present.

The minutes of the last regular meeting, held September 28, 1915, were read and approved.

The annual report of the Chairman was read by the Secretary.

The report of the Nominating Committee was presented as follows:

To the Board of Direction, Engineers' Society of Western Pennsylvania:

Dear Sirs—The Nominating Committee appointed to make nominations for Officers and Directors of the Metallurgical and Mining Section of the Engineers' Society of Western Pennsylvania for the ensuing year herewith submit the following:

For Chairman,	A. N. Diehl
For Vice Chairman,	W. L. Affelder
For Directors,	W. MacG. Shiras S. L. Goodale E. B. Reeser F. S. Slocum G. H. Deike

Respectfully submitted,
Robert Linton,
Jas. O. Handy,
Jesse J. Shuman,
Nominating Committee.

No further nominations being made, the Secretary was instructed to cast a unanimous ballot for the members named, who were thereupon declared elected.

There being no further business before the Section, the paper of the evening on "The Zinc Smelter of Today" was presented by Mr. F. E. Pierce, Consulting Engineer, New York City.

Discussion by correspondence was presented by: W. R. Ingalls, Editor, The Engineering and Mining Journal, New York, N. Y.; W. McA. Johnson, American Spelter Corporation, New York City; James O. Handy, Director, Pittsburgh Testing Laboratory, Pittsburgh.

The ensuing discussion was participated in by: Prof. H. C. Ray, School of Mines, University of Pittsburgh; Robert Linton, Mining Engr., Pittsburgh; F. F. Farnham, Chemical Engr., National Metal Molding Co., Ambridge, Pa.; Jos. Breslove, Allis-Chalmers Mfg. Co., Pittsburgh; George A. Paff, Wire Dept., Jones & Laughlin Co., Woodlawn, Pa.; and the author.

The meeting adjourned at 10:30 P. M.

Elmer K. Hiles, *Secretary.*

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Bldg., Monday, January 3, 1916, at 4:20 P. M., President A. Stucki presiding, Messrs. Snyder, Crabtree, Raymer, Neilson, Duff, Frost, Hoerr, Taylor and the Secretary being present.

The minutes of the last regular meeting, held December 6, were read and approved.

The applications of the following gentlemen having been regularly published to the Society, pursuant to the action of the Board on December 6, were duly elected to membership:

MEMBERS

Ballou, George Langdon
Bruner, Frederick
Dudley, Wray
Kenderdine, George
Manice, DeForest
O'Connor, Harry Dobson
Thomas, John Fred.

ASSOCIATE MEMBERS

Hobbs, James Clarence
Mingle, John G.

ASSOCIATE

Ramage, Edwin Church

JUNIORS

Ball, Ethan Frank
Tayman, George S.
Young, Francis E.

The applications for membership were received from the following gentlemen and their names ordered published to the Society. Assignment to the various grades of membership is as follows:

MEMBERS

Barras, Louis Robert
Callery, James D.
Higgins, Thomas
Renkin, William O.

The Secretary reported the deaths of the following members of the Society:

Lee, Richard Henry	Joined	Nov., 1915	Died	Dec. 8, 1915
Bailie, Frank H.	"	May, 1909	"	Dec. 14, 1915
Diescher, Samuel	"	Jan., 1880	"	Dec. 24, 1915

President Stucki was requested to prepare a memoir for Mr. Samuel Diescher.

President Stucki reported that he had ordered flowers sent to the residence of the Diescher family.

The report of the Secretary showing condition of the finances of the Society at the close of business November 30, having been previously audited by the Finance Committee, was approved.

The resignation of Dr. John S. Unger as a member of the Board of Direction was presented by President Stucki. Dr. Unger withdraws from the Board of Direction of the Society with regret, but owing to excessive press of matters in his office has found it impossible to attend the meetings of the Board.

The names of L. J. Affelder, George H. Danforth and Robert Linton were placed in nomination to fill the vacancy caused by the resignation of Dr. Unger. Mr. Robert Linton was declared elected and the Secretary was requested to advise Mr. Linton of the matter and to secure his acceptance.

Mr. Samuel A. Taylor presented the following resolution in commemoration of Dr. Brashear's seventy-fifth birthday, which was passed unanimously, the Secretary being requested to transmit it direct to Dr. Brashear:

WHEREAS, It has come to our attention that one of our members who has served this Society in many and various ways, as a member of its Board of Direction, as President, and by numerous addresses and papers, as well as by being its special representative at many National and International Scientific Conventions or Meetings.

These facts, coupled with the further fact that his life work, while not only National, but International as well, has been largely accomplished in our midst; and further, that while his work has been of such great value to Science, and especially Engineering Science, he has also made much Science applicable to the understanding of the layman, by presenting it in such a way as to make it more appreciated by all.

This, taken with his large work in the humanitarian aspects of Society, in our city, has caused this Society to gladly adopt the following resolutions:

RESOLVED, That the Directors of the Engineers' Society of Western Pennsylvania, in regular meeting assembled, desire to pay tribute of their high esteem for the life work and association of Dr. John Alfred Brashear to this Society on this, the Seventy-fifth Anniversary of his birth, and to wish for him many more years of active and useful life among us; and

RESOLVED FURTHER, That we accept the accomplishments of his past life as an earnest of what may be his and ours to enjoy in the years yet remaining to him; and be it

RESOLVED FURTHER, That a copy of these resolutions be sent to Dr. Brashear, and that they also be spread on the Minutes of this Society as a token of the high regard in which he is held by this Society, he being one of its Honorary Members.

(Signed) A. STUCKI, *President.*

ELMER K. HILES, *Secretary.*

The meeting adjourned at 6:00 P. M.

ELMER K. HILES, *Secretary.*

REGULAR MONTHLY MEETING.

The 350th regular monthly meeting of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Bldg., on Tuesday evening, February 29, 1916, at 8:00 o'clock, President Samuel E. Duff presiding, 129 members and visitors being present.

The minutes of the last regular monthly meeting, held December 7, were read and approved.

The Board of Direction reported the election of eleven applicants to the grade of Member, two Associate Members, one Associate, and three to the grade of Junior. Also the receipt of thirteen applications for membership and the reinstatement of one member to membership in the Society.

The following resolution prepared by the Committee on Building Code of the Society was read by Mr. W. M. Judd, who moved its adoption; whereupon it was seconded and passed unanimously:

> "WHEREAS, The Council and Mayor of the City of Pittsburgh have passed and approved an ordinance providing for the organization of the Bureau of Building Inspection in such a manner as to place the engineering work of the Bureau in the hands of competent engineers of recognized standing; be it therefore
>
> "RESOLVED, That the Engineers' Society of Western Pennsylvania expresses its commendation of the above principles embodied in the ordinance and its approval of the methods lately pursued in the selection of candidates by fair examination as to engineering qualifications and appointment in accordance with examination rating and experience."

No further business coming before the Society, the paper of the evening on "What Can Best Be Done to Advance the Interests of the Engineering Profession in the United States?" was presented by Dr. J. A. L. Waddell, Consulting Engineer, Kansas City, Mo.

The ensuing discussion was participated in by: Samuel E. Duff, Cons. Engr., Pittsburgh; Edward Godfrey, Robt. W. Hunt & Co., Pittsburgh; Dr. F. L. Bishop, Dean, University of Pittsburgh, Pittsburgh; Mr. John A. Ferguson, Secy-Engr., Building Code Commission, City of Pittsburgh; W. M. Judd, W. G. Wilkins Co., Pittsburgh; A. Stucki, Cons. Engr., Oliver Bldg., Pittsburgh; F. N. Speller, Metallurgical Engr., National Tube Co., Pittsburgh; Mr. Rayman, and the author.

Mr. A. Stucki moved that a vote of thanks be extended to Dr. Waddell for his very able paper and, upon it being seconded, was passed unanimously.

On motion, the meeting adjourned at 10:30 P. M.

ELMER K. HILES, *Secretary.*

MECHANICAL SECTION.

The annual meeting of the Mechanical Section of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Bldg., Tuesday evening, February 1, at 8:10 P. M., Chairman John A. McCulloch presiding, 95 members and visitors being present.

The minutes of the last annual meeting, held February 2, 1915, were read and approved.

The annual report of the Chairman was read by the Secretary.

The report of the Nominating Committee was presented as follows:

Officers and Members of the Mechanical Section, Engineers' Society of Western Pennsylvania:

DEAR SIRS—The Nominating Committee appointed to place nominations before the Mechanical Section of the Society for the election to be held Tuesday, February 1, 1916, held its meeting January 28, 1916, and reports as follows:

Edward D. Leland,	Chairman
Harry A. Rapelye,	Vice Chairman
George K. Smith Louis C. Frohrieb Albert Kingsbury	Directors

Respectfully submitted,
GEORGE T. SNYDER, *Chairman*
H. D. WILSON
J. L. KLINDWORTH

On motion the Secretary was requested to cast a unanimous ballot for the gentlemen nominated, who were thereupon elected.

The Chairman requested Chairman-elect E. D. Leland to take the chair.

No further business coming before the Section, the address of the retiring Chairman on "Pipe" was presented by John A. McCulloch.

The ensuing discussion was participated in by: DeForest Manice, Asst. to Gen. Mgr., A. M. Byers Co., Pittsburgh; J. C. Hobbs, Asst. to Supt., Power Stations, Duquesne Light Co., Pittsburgh; L. C. Frohrieb, Secy., Federal Engineering Co., Pittsburgh; and the author.

On motion the meeting adjourned at 10:25 P. M.

ELMER K. HILES, *Secretary.*

BOARD OF DIRECTION.

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Bldg., Monday, February 7, at 4:15 P. M., Mr. Samuel E. Duff presiding, Messrs. Snyder, Hoerr, Mott, James, Neilson, Crabtree, Stucki, Linton and the Secretary being present.

The minutes of the last regular meeting, held January 3, were read and approved.

The application of the following gentlemen, having been regularly published to the Society pursuant to the action of the Board on January 3, were duly elected to membership:

MEMBERS

Barras, Louis Robert
Callery, James D.
Higgins, Thomas
Renkin, William O.

The applications for membership were received from the following gentlemen and their names ordered published to the Society. Assignment to the various grades of membership is as follows:

MEMBERS

Aston, James
Eisenbeis, Walter Herman
Hutchinson, George Cass
Kuhn, James Irwin
Rall, Robert Otto

ASSOCIATE MEMBERS

Cunningham, Frank G.
Lynde, Charles Carleton

JUNIOR

MacMillan, Carter C.

STUDENT JUNIOR

Bilotta, Louis P.

The Secretary announced that Mr. Luther L. Knox, President of the Knox Pressed & Welded Steel Co., desired to be reinstated to membership in the Society, whereupon the Secretary was requested to place Mr. Knox's name on the Society Rolls.

The Secretary reported the death of P. H. Schedin, who died January 22, 1916.

The Secretary retired from the meeting while the election of a Secretary for the ensuing year was considered. Elmer K. Hiles was re-elected Secretary of the Society.

The resignation of Mr. William Hoopes was presented to the Board and accepted with regret.

The report of the Secretary showing the condition of the finances of the Society at the close of business December 31, having been previously audited by the Finance Committee, was approved.

The Secretary read a letter from John O'Connor, Jr., Secretary of the Smoke & Dust Abatement League, inviting the Society to become a member of the League, which was so ordered.

The Secretary presented a report from Gen. W. H. Bixby, covering the Second Pan-American Scientific Congress, which was ordered filed.

The Secretary was authorized to renew the lease on our present quarters for one year.

Mr. George H. Danforth was elected as a member of the Board, vice William Hoopes, resigned.

The meeting adjourned at 6:15 P. M.

ELMER K. HILES, *Secretary*.

REGULAR MONTHLY MEETING

The 351st regular monthly meeting of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Building, on Tuesday evening, March 21, at 8:15 P. M., President Samuel E. Duff presiding, 160 members and visitors being present.

The minutes of the last regular monthly meeting, held February 29, were read and approved.

The Board of Direction reported the election of five applicants to the grade of Member; two to the grade of Associate Member; one to the grade of Junior, and one to the grade of Student Junior. Also the receipt of ten applications for membership; the reinstatement of one member to membership in the Society, and the withdrawal of one resignation.

No further business coming before the Society, the paper of the evening on "Electric Service—Problems and Possibilities" was presented by P. Junkersfeld, Assistant to Vice President of the Commonwealth Edison Company, of Chicago.

The ensuing discussion was participated in by: Robert S. Orr, Gen. Mgr., Duquesne Light Co.; Henry Harris, Gen. Const. Agent, Duquesne Light Co.; F. Uhlenhaupt, Jr., Chf. Engr., Philadelphia Co.; W. L. McCloy, Gen. Supt., Philadelphia Co.; P. M. Lincoln, Gen. Engr., Westinghouse Elec. & Mfg. Co.; C. G. Schluederberg, Engr., Westinghouse Elec. & Mfg. Co.; William Hoopes, Elec. Engr., Aluminum Co. of America; C. Elmer Bown, Attorney, Pittsburgh; E. D. Dreifus, Statistician, West Penn Traction Co.; and the author.

It was moved by Mr. Hiles and carried unanimously that a hearty vote of thanks be given Mr. Junkersfeld for his excellent presentation of his subject.

The meeting adjourned at 10:45 P. M.

ELMER K. HILES, *Secretary*.

STRUCTURAL SECTION

The regular bi-monthly meeting of the Structural Section of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Building, Tuesday evening, March 7, 1916, at 8:20 P. M., Chairman H. R. Thayer presiding, 78 members and visitors being present.

The minutes of the last regular meeting, held January 4, 1916, were read and approved.

No further business coming before the Section, the paper of the evening on "The Extent to which Sewage Can Be Purified by the Practical Methods Now in Use" was presented by Harrison P. Eddy, of Metcalf & Eddy, Consulting Engineers, Boston.

The ensuing discussion was participated in by: Paul Didier, Prin. Asst. Engr., Baltimore & Ohio R. R., Pittsburgh; Samuel E. Duff, Cons. Engr, Pittsburgh; Louis P. Blum, W. G. Wilkins Co.; Prof. J. E. Rush, Asst. Professor of Biology, Carnegie Inst. of Technology; C. M. Reppert, Div. Engr., Bureau of Engineering, City of Pittsburgh; John M. Rice, Engineer, with Morris Knowles, Pittsburgh; Harry J. Lewis, Cons. Engr., Pittsburgh; W. C. Hawley, Gen. Supt., Pennsylvania Water Co.; Prof. George W. Case, Asst. Professor Sanitary Engineering, University of Pittsburgh; Prof. William E. Mott, Professor Civil Engineering, Carnegie Inst. of Technology; N. S. Sprague, Supt., Bureau of Engineering, City of Pittsburgh; and the author.

Mr. Lewis moved that a vote of thanks be tendered Mr. Eddy for his most valuable paper, which motion was carried unanimously, whereupon the Chairman extended the thanks of the Section to Mr. Eddy.

On motion the meeting adjourned at 10:55 P. M.

Elmer K. Hiles, *Secretary.*

METALURGICALL AND MINING SECTION

The regular bi-monthly meeting of the Metallurgical and Mining Section of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Building, Tuesday, March 28, at 8:15 P. M., Chairman A. N. Diehl presiding, 240 members and visitors being present.

The minutes of the last regular meeting, held January 25, were read and approved.

No further business coming before the Section, the paper of the evening on "The Utilization of By-Products from the Manufacture of Coke" was presented by Mr. C. G. Atwater, Manager, Agricultural Dept., The Barrett Co., New York City.

Discussion by correspondence was presented by: C. J. Ramsburg, 2nd V. P., H. Koppers Co., Pittsburgh; W. H. Blauvelt, Cons. Engr., Semet-Solvay Company, Syracuse, N. Y.; F. F. Marquard, Supt., Carnegie Steel Co., Farrell, Pa.

The ensuing discussion was participated in by: Robert Linton, Mining Engineer, Pittsburgh; W. L. Affelder, Gen. Mgr., Bessemer Coke Co.; T. V. Salt, Mgr., Allegheny By-Products Co.; Wm. P. Flint, Mechanical Engineer, Pittsburgh; James O. Handy, Director, Pittsburgh Testing Laboratory; Gustav Egloff, Chemist, Aetna Chemical Co.; Dr. H. C. Porter, Chemist, H. Koppers Co.; and the author.

Mr. Affelder expressed the thanks of the Society to Mr. Atwater for his valuable paper; also to the gentlemen presenting discussion.

The meeting adjourned at 10:40 P. M.

ELMER K. HILES, *Secretary.*

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Building, on Monday, March 6, at 4:05 P. M., President Samuel E. Duff presiding, Messrs. Snyder, Hoerr, Danforth, Neilson, Stucki, James, Linton, Crabtree, Mott, Frost and the Secretary being present.

The minutes of the last regular meeting, held February 7, were read and approved.

The application of the following gentlemen, having been regularly published to the Society pursuant to the action of the Board on February 7, were duly elected to membership:

MEMBERS

Aston, James
Hutchinson, George Cass
Eisenbeis, Walter Herman
Kuhn, James Irwin
Rall, Robert Otto

ASSOCIATE MEMBERS

Cunningham, Frank G.
Lynde, Charles Carleton

JUNIOR

MacMillan, Carter C.

STUDENT JUNIOR

Bilotta, Louis P.

The applications for membership were received from the following gentlemen and their names ordered published to the Society. Assignment to the various grades of membership is as follows:

MEMBERS

Cushing, William Channing
Gaines, Edward Cornelius
Ferguson, John Marshall
Phillips, Reginald F.
Schneider, Eugene H.

ASSOCIATE MEMBER

Barney, Harry

ASSOCIATE

Edmonds, John F.	Sanderson, William Welch

JUNIORS

Galvin, Sidney F.	Glass, Roy Charles

The Secretary announced that Mr. Marshall Williams desired to be reinstated to membership in the Society, whereupon the Secretary was requested to place Mr. Williams' name on the Society Rolls.

The Secretary reported the death of George Macbeth, who died February 11, 1916, and the Secretary requested to ask Colonel T. P. Roberts to prepare a suitable memoir after conferring with other members of the Society, and with Mr. Jerome Capen, of the Macbeth-Evans Glass Company.

The report of the Secretary showing the condition of the finances of the Society at the close of business January 31, 1916, having been previously audited by the Finance Committee, was approved.

The Secretary read a letter from Mr. Ralph D. Mershon regarding Bill S-3946 and H. R. 10845, providing for the extension of military training in Civil Educational Institutions, and it was suggested that a letter be sent to all members of the Society in regard to the above. The Secretary was authorized to send out such a letter.

The Entertainment Committee was authorized to arrange for a Smoker for the American Society of Civil Engineers, to be held Friday night, June 30.

President Duff was authorized to appoint three delegates to the Smoke and Dust Abatement League.

The meeting adjourned at 5:55 P. M.

A special meeting of the Board of Direction of the Society, called to consider a recommendation made by the Finance Committee that a Reserve Fund be established by transfer of cash from the Permanent Fund for the purpose of making the finances of the Society more elastic, was held in the Society Rooms, Oliver Bldg., Wednesday, March 15, at 4:00 P. M., President Samuel E. Duff presiding, Messrs. Snyder, Hoerr, Linton, Mott, Danforth, Raymer, Crabtree and the Secretary being present.

The following letter addressed to members of the Society and which is designed for publication to the Society in connection with the establishment of a Reserve Fund was presented to the Board for approval by the Finance Committee through A. L. Hoerr, Chairman:

"*To Members of the Society:*

This letter relates to a plan for handling the financial matters of the Society in a more convenient way than they can be handled at the present time.

Under the By-Laws, all money received must be credited to two funds; Initiation and Life Membership fees must be credited to the Permanent Fund; all other income from annual dues, advertising, etc., must be credited to the General Fund. The General Fund is used for paying the operating expenses of the Society. The Permanent Fund has been invested in bonds from time to time.

The income of the Society, exclusive of initiation fees, is sufficient to pay all operating expenses, but this income varies considerably from month to month, and there is also a variation in the operating expenses, which is independent of and different from the variation in monthly income. This at times causes the General Fund to run very low and is very inconvenient in the proper handling of financial matters, as under the By-Laws it is not possible to transfer money from the Permanent Fund to the General Fund without a vote of the Society. This, it is apparent, it would be impracticable to obtain every time the General Fund was low. It would also not be good business policy for the Society to borrow money outside at 6 percent while it owns bonds on which it receives interest at 5 percent.

In brief, on account of the large growth of the Society during the past few years, it should have a larger working capital than it has at the present time in order to provide for this variation of income and expenditure.

It is, therefore, the recommendation of the Board of Direction that a Reserve Fund be created, with a maximum limit of $2500. There are now fourteen $1000 bonds and $1288.34 cash in the Permanent Fund. The plan is to transfer this cash to the Reserve Fund until it reaches the maximum specified of $2500. After that the initiation fees will again be credited to the Permanent Fund, as at present.

The Reserve Fund will simply be used, as its name implies, as a reserve which will be drawn upon when the General Fund is low and repaid when receipts are higher than expenditures. This will avoid any temporary shortage in the General Fund to pay current bills, the only remedy for which is to ask the Society to grant, by vote, permission to make temporary use of some of the money of the Permanent Fund, or to borrow money outside at 6 percent, when the Society has its own money invested at 5 percent. This Reserve Fund will make an improvement in conditions existing at the present time; it will not in any way increase the annual expenses of the Society, and should operate to promote its development.

Your approval of this plan of creating a Reserve Fund for the reasons given is requested.

Respectfully submitted,

A. L. HOERR, *Chairman Finance Committee.*

The above letter, together with a resolution recommending to the Society the establishment of this Reserve Fund, was adopted and a letter ballot ordered in accordance with Section 10 of Article 4 of the By-Laws.

Mr. William E. Mott, Chairman, presented the following resolutions drawn up by the Publication Committee:

WHEREAS, It has been brought to the attention of the Publication Committee of the Society that a series of lectures on Military Engineering under the auspices of the four great national Societies is being presented before the engineers of New York City by U. S. Army officers, and these lectures have aroused so much interest that the capacity of three large auditoriums is taxed to accommodate the engineers desiring to hear them; and

WHEREAS, It is believed that as many engineers as possible should have an opportunity to hear these lectures in order that they may know just what engineers are called upon to do in connection with military affairs, an essential in any plan for national defense; therefore be it

RESOLVED, The Publication Committee of the Engineers' Society of Western Pennsylvania recommend to the Board of Direction that it be given authority to make the necessary arrangements for this series of lectures on Military Engineering to be presented before the engineers of Pittsburgh under the auspices of the Engineers' Society of Western Pennsylvania; be it further

RESOLVED, That the Secretary be requested to attend the lecture on Military Engineering in New York City on March 13 and to gather information regarding the necessary arrangements to be made in case the Board of Direction decides to have the lectures presented.

The recommendations of the Publication Committee were approved and the President of the Society was authorized to appoint a general committee to make arrangements for a series of lectures on Military Engineering to be presented before the engineers of Pittsburgh.

The President of the Society was duly authorized to incur any necessary expense in connection with inaugurating this movement.

The meeting adjourned at 5:25 P. M.

ELMER K. HILES, *Secretary*.

REGULAR MONTHLY MEETING

The 352nd regular monthly meeting of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Bldg., on Tuesday, April 18, 1916, at 8:24 P. M., President Samuel E. Duff presiding, forty-two members and visitors being present.

The minutes of the last regular monthly meeting, held March 21, were read and approved.

The Board of Direction reported the election of five applicants to the grade of Member, one to the grade of Associate Member, two to the grade of Associate and two to the grade of Junior. Also the receipt of eight applications for membership, the reinstatement to membership of two members and the withdrawal of one resignation.

There being no further business before the Society, the paper of the evening on "The Necessity for a National Department of National Works," by Isham Randolph, Consulting Engineer, Chicago, was presented.

The ensuing discussion was participated in by: A. Stucki, Cons. Engr., Oliver Bldg., Pittsburgh; Morris Knowles, Cons. Engr., Oliver Bldg., Pittsburgh; D. W. McNaugher, Robt. W. Hunt & Co., Pittsburgh; F. W. H. Clay, Patent Attorney, Oliver Bldg., Pittsburgh; Warren E. Emley, Asst. Chemist, National Bureau of Standards, Pittsburgh; Burd S. Patterson, Lake Erie & Ohio River Ship Canal Board, Pittsburgh; Elmer K. Hiles, Secy., Engineers' Society of Western Penna.; and the author.

It was moved that a vote of thanks be tendered Mr. Randolph, which was unanimously passed.

On motion the meeting adjourned at 10:00 o'clock.

ELMER K. HILES, *Secretary.*

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Bldg., Monday, April 3rd, at 4:00 P. M., President Samuel E. Duff presiding, Messrs. James, Danforth, Neilson, Mott, Frost, Snyder, Hoerr, Linton, Crabtree and the Secretary being present.

The minutes of the last regular meeting, held March 6th, were approved.

The application of the following gentlemen having been regularly published to the Society pursuant to the action of the Board on March 6th, were duly elected to membership:

MEMBERS

Cushing, William Channing
Gaines, Edward Cornelius
Ferguson, John Marshall
Phillips, Reginald F.
Schneider, Eugene H.

ASSOCIATE MEMBER

Barney, Harry

ASSOCIATES

Edmonds, John F.
Sanderson, William Welch

JUNIORS

Galvin, Sidney F.
Glass, Roy Charles

The applications for membership were received from the following gentlemen and their names ordered published to the Society. Assignment to the various grades of membership is as follows:

MEMBERS

Guldbraudsen, Peter
Leech, John Lemuel
Hughes, Thomas Cleveland
Leisenring, Albert Conrad
Porter, Horace C.

ASSOCIATE MEMBERS

Poague, John Henry
Tranter, George A.

JUNIOR

Argo, Reamer W.

The Secretary announced that Mr. C. F. Buente and Mr. Thomas H. Clagett desired to be reinstated to membership in the Society, whereupon the Secretary was requested to place their names on the Society Rolls.

The report of the Secretary showing the condition of the finances of the Society at the close of business February 29, 1916, having been previously audited by the Finance Committee, was approved.

Mr. George H. Neilson, Chairman of the Entertainment Committee, reported progress on arrangements for the Smoker to be tendered the members of the American Society of Civil Engineers on June 30th, and inquired regarding arrangements for financing the Smoker. The President was authorized to appoint a committee to raise $1000 or $1200 for the Smoker.

The Committee on Medal Awards presented the following report, which was approved:

Pittsburgh, Pa., March 30, 1916.

Mr. Samuel E. Duff, President,
Engineers' Society of Western Penna.

Dear Sir:

The Committee which you appointed for considering the awarding of medals for papers presented to the Society during the past year held a meeting on Thursday, March 23rd, in the rooms of the Society. All members of the Committee were present at this meeting.

Previous to the meeting each of the members of the Committee had carefully considered all of the papers for medals; in addition to this, some of the papers were submitted to the other engineers, not members of the Committee, but having more intimate and detailed knowledge of the subjects discussed by these papers. This was for the purpose of obtaining expert opinion, which was used in the final estimate of the papers. In addition to this, the matter was fully discussed with the Secretary, who was able to give important assistance to the Committee in forming their opinion. The conclusions of the Committee are as follows:

1st. That no paper that is eligible for consideration is of sufficient merit to justify the recommendation of a gold medal.

2nd. That the silver medal be awarded to Mr. John A. Hunter, for his paper entitled "Tests on a New Chain Grate Stoker and a New Method of Baffling Stirling Boilers."

3rd. That the paper of Mr. Frank M. McCullough on "Tests on Sands and Gravel in the Pittsburgh District" is entitled to favorable mention by the Committee.

Respectfully submitted,

W. E. SNYDER, *Chairman,*
ROBERT LINTON,
FREDERIC CRABTREE.

The Publication Committee made a progress report indicating that a tentative program for the year had been blocked out and it was expected that it would be completed during the next few weeks.

The Membership Committee presented a progress report.

Plattsburg Training Camp. A letter from the Pittsburgh Military Training Camps was read, asking the Society to co-operate in the matter of disseminating literature among members of the Society regarding the Plattsburg Encampment.

The Secretary was authorized to write to Mr. H. A. Rapelye, advising that the Society's office would gladly co-operate.

The meeting adjourned at 6:30 P. M.

ELMER K. HILES, *Secretary.*

BOOK REVIEWS

"THE METALLOGRAPHY AND HEAT TREATMENT OF IRON AND STEEL." By Albert Sauveur. Second Edition. 504 pages, 7¼x10½. 438 illustrations. Sauveur & Boylston, Cambridge, Mass. $6.00 postpaid.

We recommend to chemists, metallurgists and engineers the new edition of Professor Sauveur's book, "The Metallography and Heat Treatment of Iron and Steel." We have found it of much value in our own work as metallurgical engineers. The study of iron and steel is thoroughly practical as well as scientific.

In the 1916 edition of this work the author has added much important data regarding etching reagents, alloy steels, heat treatment of steel, and the recognition of impurities in iron and steel.

The only criticisms we have are that the magnifications are at so many different diameters that they do not lend themselves to quick comparisons, and that, if the etching media had been stated it would have increased the value of the photomicrographs.

This book fills a long-felt want, in that its contents are readily understood by practical steel workers, as well as by those versed in the technical and scientific sides of iron and steel metallurgy. The methods of treatment outlined in this work are such that they can be applied with excellent practical results.

G. A. WHITE and A. MILNE.

REGULAR MONTHLY MEETING

The 353rd regular monthly meeting of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Building, Tuesday, May 16, at 8:20 P. M., President Samuel E. Duff presiding, fifty members and visitors being present.

The minutes of the last regular monthly meeting, held April 18, 1916, were read and approved.

The Board of Direction reported the election of five applicants to the grade of Member; two to the grade of Associate Member; and one to the grade of Junior. Also the receipt of fourteen applications for membership, and one application for transfer to higher grade.

There being no further business before the Society, the paper of the evening, on "Scientific Methods in Construction," was presented by Sanford E. Thompson, Consulting Engineer, Boston.

The ensuing discussion was participated in by: C. D. McArthur, Chf. Engr., Blaw Steel Construction Co., Hoboken, Pa.; Kenneth Talbot, Div. Engr., Universal Portland Cement Co., Pittsburgh; A. Stucki, Consulting Engr., Pittsburgh; H. F. Layton, Consulting Engr., Pittsburgh; W. A. Weldin, Consulting Engr., Blum, Weldin & Co., Pittsburgh; and the author.

It was moved and seconded that a vote of thanks be extended to Mr. Thompson for his very excellent paper, which was passed unanimously.

On motion the meeting adjourned at 10:30 P. M.

ELMER K. HILES, *Secretary.*

METALLURGICAL AND MINING SECTION

The regular bi-monthly meeting of the Metallurgical and Mining Section of the Society was held in the Society Rooms, Oliver Building, Tuesday evening, May 23, at 8:15 o'clock, Chairman A. N. Diehl presiding, 87 members and visitors being present.

The minutes of the last meeting were read and approved.

President Duff presented the silver medal awarded by the Board of Direction through its Medal Award Committee, for the best paper presented last year, to John A. Hunter, for his paper on "Tests on a Recent Type of Chain Grate Stoker and New Method of Baffling Stirling Boilers."

There being no further business before the Section, the paper of the evening, on "Some Aspects of the Testing of Refractories," was presented by A. V. Bleininger, Ceramic Chemist, U. S. Bureau of Standards, Pittsburgh.

The ensuing discussion was participated in by: James O. Handy, Director of Research, Pittsburgh Testing Laboratory, Pittsburgh; C. E. Nesbit, Chief Chemist, Edgar Thomson Works, Carnegie Steel Co., Pittsburgh; Robert W. H. Pierce, Chf. Chemist, Harbison-Walker Refractories Co., Pittsburgh; Dr. John S. Unger, Mgr., Central Research Laboratories, Carnegie Steel Co., Pittsburgh; A. E. Smyser, Mech. Engr., H. Koppers Company, Pittsburgh; and the author.

The meeting adjourned at 10:05 P. M.

ELMER K. HILES, *Secretary.*

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Building, Monday, May 1, 1916, at 4:00 P. M., President Samuel E. Duff presiding, Messrs. Hoerr, Snyder, Stucki, Danforth, Raymer and the Secretary being present.

The minutes of the last regular meeting, held April 3, were approved.

The applications of the following gentlemen, having been regularly published to the Society pursuant to the action of the Board on April 3, were duly elected to membership:

MEMBERS

Guldbraudsen, Peter
Hughes, Thomas Cleveland
Leech, John Lemuel
Leisenring, Albert Conrad
Porter, Horace C.

ASSOCIATE MEMBERS

Poague, John Henry
Tranter, George A.

JUNIOR

Argo, Reamer W.

Applications for membership were received from the following gentlemen and their names ordered published to the Society. Assignment to the various grades of membership is as follows:

MEMBERS

Ashmead, Charles Bringhurst
Barr, George B.
Craven, James Franklin
Mandeville, J. Bradley
Norton, Edwin Kenneth
Ramsburg, Charles Joseph
Ryde, Herbert
Sturdevant, Clarence Lynn
Wisener, George Edward
Work, William Roth

ASSOCIATE MEMBERS

Davies, Thomas D.
Hardie, Alexander
Knight, Harold Chew
McGeorge, Jr., David Winfield

The application of Karl T. Stearns for transfer to higher grade was favorably considered, transfer being made to the grade of Member.

The Secretary reported the death of Mr. Alexander Coulter, who joined the Society in January, 1901, and died April 13, 1916.

The Secretary was requested to write Mr. George W. Hutchinson, asking him to prepare a memoir for Mr. Coulter.

The report of the Secretary showing the condition of the finances of the Society at the close of business March 31, 1916, having been previously audited by the Finance Committee, was approved.

The Secretary announced that the Entertainment Committee would hold a meeting during the current week and was requested to advise the members of the Board regarding the plans of the Entertainment Committee for the smoker, in which their good interest was manifested, before the June meeting of the Board.

The meeting adjourned at 5:00 P. M.

ELMER K. HILES, *Secretary*.

REGULAR MONTHLY MEETING

The 354th regular monthly meeting of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Building, Tuesday, June 6th, at 8:23 P. M., President Samuel E. Duff presiding, sixty-nine members and visitors being present.

The minutes of the last regular meeting, held May 16th, were read and approved.

Mr. A. L. Hoerr, Chairman of the Finance Committee, announced the result of the ballot on a reserve fund, there being 239 approving and 7 disapproving ballots.

Mr. Harry Lewis offered a resolution of thanks to the gentlemen who participated in the course of Military Engineering Lectures given the past month by the Society, including also the Committee that arranged the course, which was carried by unanimous vote.

Mr. C. D. Terry reported for the Entertainment Committee, announcing some of the details in connection with the Smoker and Entertainment to be tendered by the Society to visiting members of the American Society of Civil Engineers on the occasion of its 48th Annual Convention.

The Board of Direction reported the election of ten applicants to the grade of Member and four to the grade of Associate Member and the receipt of eight applications for membership; also the reinstatement of one member to membership in the Society and one transfer to higher grade.

There being no further business before the Society, the paper of the evening on "The Glacial Epoch" was read by Thomas P. Roberts, Civil Engineer, U. S. Engineer Office, Pittsburgh.

The ensuing discussion was participated in by: Mr. Richard R. Hice, State Geologist of Penna., Beaver, Pa.; Dr. A. E. Ortmann, Carnegie Museum, Pittsburgh; Mr. Hudson F. Layton, Cons. Engr., 432 Diamond St., Pittsburgh; Prof. Charles R. Fettke, Carnegie Institute of Technology, Pittsburgh; Prof. Henry Leighton, School of Mines, University of Pittsburgh, and the author.

On motion the meeting adjourned at 11:00 P. M.

ELMER K. HILES, *Secretary*.

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Building, June 5th, 1916, at 4:10 P. M., President Samuel E. Duff presiding, Messrs. Neilson, Raymer, James, Danforth, Crabtree, Stucki, Linton, Snyder, Hoerr, and the Secretary being present.

The minutes of the last regular meeting, held May 1st, were approved.

The applications of the following gentlemen having been regularly published to the Society pursuant to the action of the Board on May 1st were duly elected to membership:

MEMBERS

Ashmead, Charles Bringhurst
Barr, George B.
Craven, James Franklin
Mandeville, J. Bradley
Norton, Edwin Kenneth
Ramsburg, Charles Joseph
Ryde, Herbert Holmes
Sturdevant, Clarence Lynn
Wisener, George Edward
Work, William Roth

ASSOCIATE MEMBERS

Davies, Thomas D.
Hardie, Alexander
Knight, Harold Chew
McGeorge, Jr., David Winfield

Applications for membership were received from the following gentlemen and their names ordered published to the Society. Assignment to the various grades of membership is as follows:

MEMBERS

Bradshaw, Grant David
Follet, Louis
Lanpher, Erwin E.
Smith, Newton Guy
Spielmann, John A.

ASSOCIATE MEMBERS

Pendleton, Hugh Nelson
Vansant, William Laurence
Warner, Charles Kenneth

The Secretary read a letter from Mr. C. C. Jett, asking to be reinstated to membership in the Society, whereupon the Secretary was requested to place his name on the Society Rolls.

Application for transfer to higher grade was presented by J. C. Hobbs, whereupon he was transferred to the grade of Member.

The Secretary reported the death of Mr. Chester B. Albree, who joined the Society in 1885 and died May 27, 1916. He was elected president of the Society in 1903.

Mr. J. H. MacRoberts joined the Society in 1881 and was a life member of the Society. He died in the Spring of 1916.

The report of the Secretary showing the condition of the finances of the Society at the close of business April 30, 1916, having previously been audited by the Finance Committee, was approved.

Mr. George H. Neilson, Chairman of the Entertainment Committee, presented a verbal report announcing that affairs in connection with the proposed Smoker for the American Society of Civil Engineers was well under way.

Prof. Crabtree made a favorable report for the House Committee, advising that Albert Kingsbury and Sumner B. Ely had been appointed to this Commitee.

Mr. James made a favorable report for the Membership Committee.

The Secretary read Prof. Mott's report for the Publication Committee. which advised that the program for the ensuing year had been practically completed with the exception of perhaps six papers.

The matter of the continuation of the Competition in Engineering Problems conducted by the Committee on Engineering Education for the past three years was discussed. President Duff advised that the matter had all been laid before the members of this Committee and that a letter ballot among the members of the Committee, which had been conducted, was practically unanimous in the advisability of discontinuing the Competition.

After discussion, it was agreed to discontinue the Competition in Engineering Problems.

The Secretary introduced the reports of the Judges of the solutions received in the Competition in Engineering Problems presented, and the awards as made by the judges were approved.

The Secretary announced the result of the letter ballot on the establishment of a Reserve Fund, the report being as follows:

Total number of members voting yea	239
Total number of members voting nay	7
Total number of votes	246

The report was ordered accepted and filed, and the Treasurer and Secretary authorized to arrange for the establishment of the fund.

President Duff introduced the matter of having sent telegrams to the various Congressmen and Senators protesting against the so-called Anti-Efficiency Legislation as set forth in H. R. Bill No. 8665 and amendments to the Civil, Naval, Army, Fortifications or Postal Appropriation Bills. His action was fully approved.

The meeting adjourned at 6:05 P. M.

ELMER K. HILES, *Secretary*.

REGULAR MONTHLY MEETING

The 355th regular monthly meeting of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Bldg., Tuesday evening, September 19, 1916, at 8:15 o'clock, President Samuel E. Duff presiding, 176 members and visitors being present.

The minutes of the last regular meeting, held June 6, were read and approved.

The minutes of the September 11 meeting of the Board of Direction were read, announcing the election of six Members, two Associate Members and one Associate and the receipt of four applications for membership.

The appointment of a Committee on Rapid Transit, in response to a request made by Mayor Armstrong, was announced.

The minutes of a special meeting of the Board of Direction, held September 18, were read, announcing the approval, in general, of the draft of revised Smoke Regulation Ordinance.

No further business coming before the Society, the paper of the evening on "The Hell Gate Bridge" was presented by Jacob Lowenstein, Engineer, American Bridge Co., New York.

The paper was illustrated by some exceptionally fine lantern slides, and moving pictures illustrating the methods of construction were also shown. An extended discussion followed the presentation of the paper.

It was moved and carried unanimously that a vote of thanks be extended Mr. Lowenstein for his interesting presentation of the erection of the Hell Gate Bridge.

The meeting adjourned at 10:45 P. M.

Elmer K. Hiles, *Secretary*.

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Bldg., Monday, September 11, 1916, at 4 P. M., President Samuel E. Duff presiding, Messrs. Mott, Danforth, Neilson, James, Hoerr, Raymer and the Secretary being present.

The minutes of the last regular meeting, held July 31, were read and approved.

The applications of the following gentlemen, having been regularly published to the Society, pursuant to the action of the Board on July 31, were duly elected to membership:

MEMBERS

Baker, Walter Hudson
Eby, Earl Ellsworth
Griffith, Lawrence Wright
Hulbert, Everson C.
Miller, Ulysses Grant
Smith, Charles Henry

ASSOCIATE MEMBERS

Marcus, Morris M.
Schwartz, Benjamin

ASSOCIATE

Webb, George C.

The applications of the following gentlemen were received and their names ordered published to the Society. Assignment to the various grades of membership is as follows:

MEMBERS

Cooper, Maurice Diehl
Egan, Frank L.
McEwen, Fred Bates
Wilder, Warren

Reports of the Secretary showing the financial condition of the Society at the close of business July 31 and August 31, having been previously audited by the Finance Committee, were approved.

The Entertainment Committee reported that the Annual Banquet would be held in December this year, probably on the 11th of the month. A tentative selection of speakers has been made.

The Committee expects to arrange for other activities during the Fall.

There was an informal discussion of the proposed plan of the Membership Committee presented by Chairman H. D. James.

Chairman William E. Mott presented a verbal report for the Publication Committee, advising of a special meeting of the Society to be held on Wednesday evening, October 25, in "Smoke Abatement Week," Mr. Osborn Monnett presenting a paper on "Engineering Phases of Smoke Abatement."

It was moved and seconded that the Chairmen of the several committees of the Society make monthly reports covering the activities of their committees at the regular monthly meetings of the Society.

President Duff was authorized to appoint a Committee on Rapid Transit in response to a request made by Mayor Armstrong.

The meeting adjourned at 5:50 P. M.

A special meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Bldg., on Monday, September 18, at 4:10 P. M., President Duff presiding, Messrs. Hoerr, Snyder, Stucki, Mott, Raymer, Linton, Crabtree and the Secretary being present.

President Duff introduced the subject for the consideration of which the special meeting of the Board was called, i. e., the consideration of the proposed changes in the ordinance relating to smoke regulation in the City of Pittsburgh.

Mr. J. W. Henderson, Chief of the Bureau of Smoke Inspection, appeared before the Board and discussed the proposed changes in the ordinance relating to smoke regulation. After answering several questions Mr. Henderson was thanked and excused from further attendance at the meeting.

After a further discussion of the general matter of the revised ordinance which is shortly to be presented to Council, it was moved that President Duff be authorized to address a letter to Mr. J. W. Henderson, approving in general the draft of the revised ordinance with the understanding that the period allowed for dense smoke when starting fires should remain twenty minutes, as in the present ordinance. This motion was carried.

The meeting adjourned at 5:04 P. M.

ELMER K. HILES, *Secretary*.

REGULAR MONTHLY MEETING

METALLURGICAL AND MINING SECTION

The regular bi-monthly meeting of the Metallurgical and Mining Section of the Society was held in the Society Rooms, Oliver Bldg., on Tuesday evening, Sept. 26, 1916, at 8:20 o'clock, Vice Chairman W. L. Affelder presiding, 80 members and visitors being present.

The minutes of the last meeting were read and approved.

No further business coming before the Section, the paper of the evening, on "New Mining Methods as Practiced by the H. C. Frick Coke Company," by Patrick Mullen, Mine Inspector, H. C. Frick Coke Co., Scottdale, Pa., was read.

The ensuing discussion was participated in by: W. L. Affelder, Gen. Mgr., Bessemer Coke Co., Pittsburgh; R. W. Argo, Mech. Engr., H. Koppers Co., Pittsburgh; G. S. Baton, Mining Engr., Pittsburgh; J. A. Burns, Mine Foreman, Thompson-Connellsville Coke Co., Republic, Pa.; J. W. Campbell, Div. Engr., H. C. Frick Coke Co., Scottdale, Pa.; R. M. Keeney, Mine Supt., Thompson-Connellsville Coke Co., New Salem, Pa.; A. B. Kelly, Supt., Bessemer Coke Co., Greensburg, Pa.; W. W. MacFarren, Cons. Mech. Engr., Pittsburgh; John Sincock, Asst. Gen. Supt., W. J. Rainey, Uniontown, Pa.; G. K. Smith, Mech. Engr., Westmoreland Coal Co., Pittsburgh; E. J. Taylor, Chf. Engr., Pittsburgh Coal Co.; Robert Linton, Mining Engr., Pittsburgh, Pa.; J. T. Ryan, V. P. & Gen. Mgr., Mine Safety Appliances Co., Pittsburgh; W. A. Weldin, Blum, Weldin & Co., Pittsburgh; Robert Wood, Jr., Asst. to Gen. Supt., W. J. Rainey, Uniontown, Pa., and the author.

It was moved and seconded that a vote of thanks be tendered Mr. Mullen for his most excellent paper, and was passed unanimously.

The meeting adjourned at 9:42 P. M.

ELMER K. HILES, *Secretary.*

MECHANICAL SECTION

The regular bi-monthly meeting of the Mechanical Section was held in the Society Rooms, Oliver Bldg., Tuesday evening, Oct. 3, 1916, at 8:07 o'clock, Chairman E. D. Leland presiding, 170 members and visitors being present.

The minutes of the last meeting, held April 4, 1916, were read and approved.

There being no further business before the Section, the paper of the evening, on "Electrically-Driven Reversing Rolling Mills," was presented by Mr. Wilfred Sykes, General Engineer, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

The ensuing discussion was participated in by: William Ahlen, Chf. Engr., Duquesne Works, Carnegie Steel Co., Duquesne, Pa.; S. C. Coey, Asst. Master Mechanic, Youngstown Sheet & Tube Co., Youngstown, O.; A. F. Backlin, Cons. Engr., American Steel & Wire Co., Pittsburgh; Brent Wiley, Mgr. Mill Section, Industrial Dept., Westinghouse Elec. & Mfg. Co.; W. E. Snyder, Mech. Engr., American Steel & Wire Co., Pittsburgh; F. I. Ellis, Supt. Pipe Mills, Jones & Laughlin Steel Co., Pittsburgh; F. Waldorf, Field Engr., Pittsburgh Valve Fdry. & Const. Co.; F. C. Biggert, Jr., Chf. Engr., United Engrg. & Fdry. Co., Pittsburgh; Norman W. Storer, Gen. Engr., Westinghouse Elec. & Mfg. Co., East Pittsburgh, and the author.

It was moved and seconded that a vote of thanks be extended to Mr. Sykes for his very interesting paper, which was passed unanimously.

On motion the meeting adojourned at 9:55 P. M.

Elmer K. Hiles, *Secretary.*

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Bldg., Monday, Oct. 2, 1916, at 4 P. M., President Samuel E. Duff presiding, Messrs. Snyder, Linton, Danforth, James, Crabtree, Hoerr, Mott and the Secretary being present.

The minutes of the last regular meeting, held Sept. 11, were approved without reading.

The applications of the following gentlemen, having been regularly published to the Society, pursuant to the action of the Board on Sept. 11, were duly elected to membership:

MEMBERS

Cooper, Maurice Diehl
Egan, Frank L.
McEwen, Fred Bates
Wilder, Warren

The applications of the following gentlemen were received and their names ordered published to the Society. Assignment to the various grades of membership is as follows:

MEMBERS

Baton, George S.	Dunsford, Jan Rubidge
Campbell, John W.	Moore, Spencer Frank

ASSOCIATE MEMBERS

Duncan, George	Simmons, Franklin Allen

JUNIOR

Hukill, Henry Darbin

In the unexpected absence of Mr. George H. Neilson, the Secretary reported that arrangements were under way for the Annual Reception and Dance, which is to be held at the Hotel Schenley on Friday evening, November 3.

The Entertainment Committee is very desirous of holding an inspection trip during the early part of October, and members of the Board were urgently requested to make suggestions as to possible inspection trips.

Professor Crabtree, Chairman of the House Committee, made a progress report, announcement being made to the Board that it would be necessary for the Society to move its quarters from the Oliver Bldg. on the first of May, 1917. A tentative layout of a corner of one floor in the Chamber of Commerce Bldg. was accepted.

Mr. H. D. James, Chairman of the Membership Committee, presented a progress report covering a general statement of the proposed plan that the Committee has in mind for its work. Among other things, the Membership Committee recommended that a list of names of prominent men in the district known to be eligible for membership in the Society be prepared and presented to the Board of Direction for its approval, the idea being that an invitation be extended to these men to join the Society, without going through with the red tape of filling out and signing an application blank.

The matter was discussed fully and, being concurred in, it was moved and seconded that the recommendation be approved. The motion carried.

It was suggested that the Membership Committee submit in detail its general plans.

The Secretary presented a letter from Mr. H. W. Wood, Chairman of the Conference Committee on National Preparedness, requesting the Society to pass certain resolutions urging the principle of Universal Military Service.

The matter was discussed and it was concluded that the matter was rather out of the general line of activities of the Society and the letter was ordered tabled.

The meeting adjourned at 5:20 P. M.

ELMER K. HILES, *Secretary.*

REGULAR MONTHLY MEETING

The 356th regular monthly meeting of the Engineers. Society of Western Pennsylvania, was held in the Society Rooms, Oliver Building, Wednesday evening, October 25, 1916, at 8:15 P. M., President Samuel E. Duff presiding, 130 members and visitors being present.

The minutes of the last regular monthly meeting were read and approved.

The minutes of the October 2 meeting of the Board of Direction were read, announcing the election of four applicants to the grade of Member and the receipt of seven applications for membership; also the receipt of one resignation.

Mr. George S. Davison moved that a Committee be appointed to consider and report on a memorial for George Westinghouse, and presented the following resolution, which was passed unanimously:

> WHEREAS, Mr. George Westinghouse was, at the time of his death, and for many years previous thereto, a citizen of this community; was a most persistent and indefatigable worker upon problems involving the safety and comfort of mankind; and as an inventor and engineer was the most widely and favorably known man of his time; and
>
> WHEREAS, this community would do honor to itself by preserving his name to posterity by a suitable memorial, which would at the same time be a lasting benefit to the public, of which he was proud to be the servant; and
>
> WHEREAS, The Engineers' Society of Western Pennsylvania is the proper body to initiate such a project; therefore be it
>
> RESOLVED, that this Society, through its President, appoint a committee of five members, to be known as the Westinghouse Memorial Committee, who shall investigate a plan for the purchase of the former home of Mr. Westinghouse, known as "Solitude," consisting of ten acres of land, converting same into a public park, to be forever known as "Westinghouse Park," erecting thereon a suitable memorial, and turning the whole over to the City of Pittsburgh, under its guarantee that the gift shall receive the same care and protection as other parks owned by the city.
>
> The Committee shall estimate the cost of this undertaking and shall make a canvass for the necessary funds and report back to the Society.

President Samuel E. Duff appointed Messrs. George S. Davison, Chairman; Julian Kennedy, William L. Scaife, Charles F. Scott and E. B. Taylor on the committee.

There being no further business before the Society, the paper of the evening on "Engineering Phases of Smoke Abatement" was presented by Mr. Osborn Monnett, Engineer, American Radiator Co., formerly Chief Smoke Inspector, City of Chicago.

STRUCTURAL SECTION

e regular bi-monthly meeting of the Structural Section of the ers' Society of Western Pennsylvania was held in the Society s, Oliver Building, Tuesday evening, October 31, 1916, at 8:15 ., Chairman Horace R. Thayer presiding, 64 members and visitors present.

e minutes of the last regular meeting held March 7, 1916, were d approved.

hairman Thayer appointed the following Nominating Committee to ate officers for the ensuing year:

M. Judd T. J. Wilkerson P. S. Whitman.

o further business coming before the Section, the papers of the r, on "Factors Affecting Costs of Structural Steel Shop Work," parts, was presented by Mr. Smith (reading for Mr. E. W. Pitt-d Mr. Danforth.

ten discussion was presented by: R. A. Pendergrass, Engineer, h Plant, McClintic Marshall Co.; J. A. McEwen, Sales Man-ttsburgh Bridge and Iron Works, Pittsburgh; Samuel E. Duff, Engineer, Pittsburgh; Horace R. Thayer, Assistant Professor al Design, Carnegie Institute of Technology; G. W. Nichols, r, S. C. Webb Engineering Co., Pittsburgh; P. S. Whitman, r, Riter Conley Manufacturing Co., Pittsburgh.

nsuing discussion was participated in by: L. F. W. Hildner. gineer, Pittsburgh Bridge and Iron Works, Rochester, Pa.; kerson, Division Engineer of Bridges, Bureau of Engineering, Pittsburgh; J. E. Banks, Engineer, Bureau of Standards, Ameri-e Co.; Mr. Uhl, Chief Engineer, Memphis Steel Construction sburg, Pa., and the author.

motion, the meeting adjourned at 10:23 P. M.

Elmer K. Hiles, *Secretary.*

METALLURGICAL SECTION

gular bi-monthly meeting of the Metallurgical and Mining the Society was held in the Society Rooms, Oliver Building, ening, November 28, 1916, at 8:15 P. M., Chairman A. N. ing, 260 members and visitors being present.

nutes of the last regular meeting, held September 26, were roved.

ing no further business before the Section, the paper of the "A Personally Conducted Trip to the Koppers' By-Product as Plant of the LaClede Gas Co., St. Louis" was presented Ramsburg, Second Vice President of the H. Koppers Co.

ing discussion was participated in by: W. E. Fohl, Consulting Mining Engineer, Pittsburgh; M. R. Brode; W. L. Affelder, General Manager, Bessemer Coke Co., Pittsburgh; J. W. Dougherty, Estimator, Coal Handling Machinery, Heyl & Patterson, Inc., Pittsburgh; H. C. Cronemeyer, Engineering Department, Jones & Laughlin Steel Co.; Frank L. Egan, H. Koppers Co., Pittsburgh; Lewis Vincent, Assistant Gas Engineer, Riter Conley Manufacturing Co., Pittsburgh; B. S. Rederer, Manager, B. S. Rederer & Co., Pittsburgh; Samuel E. Duff, Consulting Engineer, Pittsburgh; Harry J. Lewis, Consulting Engineer, Pittsburgh; A. N. Diehl, Assistant General Superintendent, Carnegie Steel Co., Duquesne, Pa., and the author.

It was moved that a vote of thanks be extended to Mr. Ramsburg for his very fine presentation of this interesting subject, which was passed unanimously.

On motion, the meeting adjourned at 10 P. M.

ELMER K. HILES, *Secretary*.

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Building, Monday, November 6, 1916, at 4:10 P. M., President Samuel E. Duff presiding, Messrs. Stucki, Danforth, James, Raymer, Snyder, Crabtree, Mott, Frost and George H. Neilson acting as Secretary, being present.

The minutes of the last regular meeting, held October 2, 1916, were approved without reading.

The applications of the following gentlemen, having been regularly published to the Society, pursuant to the action of the Board on October 2, were duly elected to membership:

MEMBERS

Baton, George S.
Campbell, John W.
Dunsford, Jan Rubidge
Moore, Spencer Frank

ASSOCIATE MEMBERS

Duncan, George
Simmons, Franklin Allen

JUNIOR

Hukill, Henry Darbin

The applications of the following gentlemen were received and their names ordered published to the Society. Assignment to the various grades of membership is as follows:

MEMBERS

Blickman, John Alex.
Dougherty, James W.
McKee, William Meek
Snyder II, George W.

JUNIORS

Day, Cecil Thurlow
Neale, Richmond Hughes

The Secretary read a letter from Mr. S. R. Bachtel, asking to be reinstated to membership in the Society, whereupon the Secretary was requested to place his name on the Society Rolls

The report of the Secretary, showing the financial condition of the Society at the close of business, September 30, 1916, having been previously audited by the Finance Committee, was approved.

The Nominating Committee presented the following report:

"Pittsburgh, Pa., Nov. 6, 1916.

Mr. Samuel E. Duff, Pres.,
Engineers' Society of Western Penna.

Dear Sir:

The Nominating Committee, appointed by the President, has had two meetings, one on October 19 and the other October 27, a majority of the Committee being present in each case. After considerable discussion of the suggestions made by letter by the membership, the following names are recommended:

President, A. L. Hoerr
Vice President, George H. Neilson
Treasurer, A. E. Frost
Directors, E. W. Pittman, George H. Barbour.

The Nominating Committee would further bring to the attention of the Board a condition which now exists, that is bound to create an embarrassing situation for each Nominating Committee. The interests of the Society are undoubtedly best served by having the personnel of the body that has to do with the direction of the Society's affairs changed very gradually, and it is undoubtedly best for the Society's interests that the man serving as Vice President be advanced to the Presidency; also, that a man who has served three years as Director, be advanced to the Vice Presidency. This latter point, however, makes it necessary for the Nominating Committee to choose one of two men for Vice President, the other automatically passing out of the Board, notwithstanding his active service for at least three years for the good of the Society. We believe that this condition is many times unfair to the man who cannot be selected for the Vice Presidency, and that some change should be made in the By-Laws and in practice which will avoid the situation which now makes it necessary for the Nominating Committee to say which of two men shall continue on until he is made President, and which one shall be passed out of the directorate. We realize that any change will undoubtedly require careful consideration and discussion; nevertheless, it should be taken up as being for the best interest of the Society and in fairness to all the men who serve properly as Directors.

Yours truly,

(Signed) W. E. Snyder
W. C. Hawley
George T. Ladd
Lee C. Moore
S. A. Taylor."

In accordance with the By-Laws, the Board passed on the eligibility of candidates who were approved and the report of the Committee accepted.

A letter from Mr. Louis P. Blum, addressed to the Board, suggesting that the Board urge upon the appointing power the advisability of appointing a Pittsburgh engineer as Commissioner of Transit, was read and ordered filed.

The President reported to the Board a resolution presented at the last meeting of the Society by Mr. George S. Davison, with regard to establishing a Westinghouse Memorial, advising that the Society had authorized the President to appoint a committee to examine into this project.

A letter from the Committee on Nitrate Plant of the Nashville Section of the Engineering Association of the South was read, urging this Society to take action in connection with the establishment of a Nitrate Plant at Muscle Shoals in the Tennessee River by the United States Government. After consideration, it was thought advisable not to take action in this matter.

The meeting adjourned at 5:45 P. M.

George H. Neilson, *Acting Secretary.*

REGULAR MONTHLY MEETING

The 358th regular monthly meeting of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Building, Tuesday, December 12, 1916, at 8:15 P. M., President Samuel E. Duff presiding, 108 members and visitors being present.

The minutes of the last regular monthly meeting, held November 21, 1916, were read and approved.

The minutes of the December 4th meeting of the Board of Direction were read, announcing the election of four applicants to the grade of Member and two to the grade of Junior; also the receipt of three applications for membership and the reinstatement of one member.

Mr. A. Stucki asked that some member of the Society who signed nomination papers for additional nominations explain the purpose in view, but no one replied to his request; whereupon President Duff stated that the additional nominations were made under authority of a provision in the By-Laws making it possible for ten members to make additional nominations.

Under the head of new business Mr. Lee C. Moore presented a resolution calling for subscriptions to the Brashear Memorial Fund to purchase and maintain the old South Side home of Dr. John A. Brashear, a former president of the Society:

> "In view of the fact that Dr. John A. Brashear is one of our three Honorary Members and a beloved past president of the Society, I wish to make the motion that our members be given an opportunity to forward contributions to this fund and that our Secretary, Elmer K. Hiles, be appointed Treasurer for the fund, and
>
> Further, that a notice to this effect be sent to all members of the Society at once."

The motion, being seconded, was carried unanimously.

There being no further business, the paper of the evening, on "Blast Furnace and Steel Mill Power Plants," was presented by Mr. Richard H. Rice, on behalf of himself and Sanford A. Moss, joint authors of the paper.

Written discussion was received from the following gentlemen:

Prof. Willibald Trinks, Professor Mechanical Engineering, Carnegie Institute of Technology; Mr. Frederic Otteson, Chf. Engr., Gas Engine Dept., Mesta Machine Co., Pittsburgh; Mr. A. N. Diehl, Asst. Gen. Supt., Carnegie Steel Co., Duquesne, Pa.; Mr. P. M. Lincoln, Commercial Engr., Westinghouse Elec. & Mfg. Co., East Pittsburgh; Mr. B. R. Shover, 1073 Frick Bldg., Pittsburgh; Mr. W. O. Renkin, Chf. Engr., A. M. Byers Co., Pittsburgh; Mr. Sydney Dillon, Chf. Engr., Carnegie Steel Co., Pittsburgh; Mr. S. B. Bannister, National Tube Co., Pittsburgh; Mr. A. J. Boynton, Supt., Blast Furnaces, National Tube Co., Lorain, O.; Dr. John S. Unger, Mgr., Central Research Bureau, Carnegie Steel Co., Pittsburgh; and the author.

Dr. Unger moved that a vote of thanks be extended to Mr. Rice for his paper, which motion was passed unanimously.

The meeting adjourned at 10:27 P. M.

ELMER K. HILES, *Secretary.*

SPECIAL MEETING

A special meeting of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Building, Pittsburgh, Tuesday Tuesday, December 19, at 8:20 P. M., President Samuel E. Duff presiding, 75 members and visitors being present.

This being a special meeting and only one order of business, the address of the evening was presented by Mr. D. Robert Yarnell, Vice President of the Nelson Valve Company and a Vice President of the Engineers' Club of Philadelphia, on "Engineering Co-Operation and Fellowship."

The ensuing discussion was participated in by: A. Stucki, Cons. Engr., Pittsburgh; H. D. James, Asst. to Mgr. of Engineering, Westinghouse Elec. & Mfg. Co., East Pittsburgh; Thomas Fleming, Jr., Chester & Fleming, Pittsburgh; John A. Ferguson, Secy.-Engr., Building Code Committee of Council, City of Pittsburgh; Kenneth Talbot, Div. Engr., Inspection and Information Bureau, Universal Portland Cement Co., Pittsburgh; Elmer K. Hiles, Secy., Engineers' Society of W. Penna.; P. W. Price, Asst. Engr., County Engineer's Office, Pittsburgh; John N. Chester, Cons. Engr., Chester & Fleming, Pittsburgh; N. S. Sprague, Supt., Bureau of Engineering, City of Pittsburgh; Prof. Horace R. Thayer, Asst. Professor Structural Design, Carnegie Institute of Technology; C. M. Reppert, Engr., Bureau of Engineering, City of Pittsburgh; C. R. Irvin, Engr., Richard Irvin & Co., Pittsburgh; and the author.

It was moved and carried unanimously that a vote of thanks be extended to Mr. Yarnell for his address.

On motion, the meeting adjourned at 10:30 P. M.

ELMER K. HILES, *Secretary.*

SPECIAL MEETING

A special meeting of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Building, Tuesday, December 27, 1916, at 8:32 P. M., President Samuel E. Duff presiding, 75 members being present.

At the request of the President, the Secretary read the call for the meeting, as follows:

"Pittsburgh, Pa., Dec. 16, 1916.

To the President,
Engineers' Society of Western Penna.

Dear Sir:

We have just received a circular advocating the election of certain candidates for office in the Society, and stating that these candidates promise certain reforms in the conduct of the affairs of the Society.

Believing that the matters referred to are of such importance that they should be discussed at a meeting of the Society held prior to the election of officers, we would respectfully request you to call a special meeting, limited to members only, for the purpose of securing a full and frank discussion of the principles involved.

Respectfully submitted,

GEORGE S. DAVISON,
LOUIS P. BLUM,
JOHN A. FERGUSON,
EMIL SWENSSON,
W. A. WELDIN,
JAMES O. HANDY,
S. L. TONE,
W. C. HAWLEY,
E. K. MORSE,
N. S. SPRAGUE,
CHARLES M. REPPERT,
T. J. WILKERSON."

The meeting was thereupon opened for discussion. The ensuing discussion was participated in by: George S. Davison, R. A. Cummings, N. S. Sprague, John A. Ferguson, Louis P. Blum, E. W. Pittman, S. A. Taylor, George H. Neilson, C. M. Reppert, W. E. Snyder, W. C. Hawley, A. Stucki and Samuel E. Duff.

Mr. Davison moved that a committee of five be appointed by the President of the Society, the Committee to send out requests to the membership at large for suggestions as to the betterment of the Society. The committee to bring suggestions together in concrete form at some future meeting of the Society, report suggestions and have a discussion of the Society on the recommendations made by said committee.

Discussion was offered upon this motion by: N. S. Sprague, George S. Davison, Morris Knowles, Thomas Fleming, Jr., Elmer K. Hiles, Samuel E. Duff and L. P. Blum, whereupon Mr. Davison withdrew his motion.

There being no further discussion, the meeting adjourned at 11:40 P. M.

ELMER K. HILES, *Secretary.*

METALLURGICAL SECTION

The regular monthly meeting of the Mechanical Section was held in the Society Rooms, Oliver Building, Tuesday evening, December 5, 1916, at 8:20 P. M., Chairman E. D. Leland presiding, 72 members and visitors being present.

The minutes of the last meeting, held October 3, 1916, were read and approved.

The subject of the Brashear Memorial Association's undertaking to purchase and maintain the old home of our former President was brought up by Mr. Lee C. Moore, with the suggestion that the Society offer its members opportunity to contribute to that fund. While formal action could not be taken until the regular monthly meeting, yet notice was given that the subject would be presented, and meanwhile subscriptions would be received by the Secretary.

No further business coming before the Section, the paper of the evening, on "The Window Glass Machine," was presented by Mr. Robert Linton.

The ensuing discussion was participated in by: R. L. Frink, Pres., Frink Laboratories, Lancaster, O.; A. Stucki, Consulting Engineer, Pittsburgh; Samuel E. Duff, Consulting Engineer, Pittsburgh; W. E. Snyder, Mech. Engr., American Steel & Wire Co., Pittsburgh; Elmer K. Hiles, Secretary, Engineers' Society of Western Penna.; Samuel M. Kintner, Gen. Mgr., National Electric Signaling Co., Pittsburgh; W. M. Judd, Engineer, W. G. Wilkins Co., Pittsburgh; Thomas C. McKinley, Supt., American Window Glass Co., Belle Vernon, Pa.; H. F. Clark, American Window Glass Co., Pittsburgh; Dr. F. L. Bishop, Dean, School of Engineering, University of Pittsburgh; and the author.

On motion, the meeting adjourned at 10:20 P. M.

ELMER K. HILES, *Secretary*.

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the Society Rooms, Oliver Building, Monday, December 4, 1916, at 4:10 P. M., President Samuel E. Duff presiding, Messrs. Snyder, Neilson, Mott, James, Danforth, Crabtree, Hoerr and the Secretary being present.

The minutes of the last regular meeting, held November 6, were approved without reading.

The applications of the following gentlemen having been regularly published to the Society, pursuant to the action of the Board on November 6, were duly elected to membership:

MEMBERS

Blickman, John Alex.	McKee, William Meek
Dougherty, James W.	Snyder II, George W.

JUNIORS

Day, Cecil Thurlow	Neale, Richmond Hughes

The applications of the following gentlemen were received and their names ordered published to the Society. Assignment to the various grades of membership is as follows:

MEMBERS

Coxe, Edward Haviland	Morse, George Hart

JUNIOR

Young, Vertrees

The Secretary read a letter from J. Spotts McDowell, asking to be reinstated to membership in the Society, whereupon the Secretary was requested to place his name upon the Society Rolls.

Letters of resignation from the following gentlemen were read by the Secretary, whereupon their resignations were ordered accepted:

Bell, Harvey W.	Joined May, 1915
Hyde, William H.	Joined Apr., 1907
Klingelhofer, Charles T.	Joined May, 1903

The report of the Secretary showing the financial condition of the Society at the close of business October 30, 1916, having been previously audited by the Finance Committee, was approved.

The following letter was read by the Secretary:

"Pittsburgh, Pa., Dec. 1, 1916.

Board of Direction,

Engineers' Society of Western Penna.,

Oliver Bldg., Pittsburgh, Pa.

Gentlemen:

In accordance with Article V, Section No. 6 of the By-Laws adopted at the 270th Regular Meeting of the Society, December 18, 1906, and subsequently amended, we, the undersigned, corporate members of the Engineers' Society of Western Pennsylvania, beg to submit the following additional nominations for officers and directors to be voted upon at the next Annual Election of the Society, to be held in January, 1917:

President	John N. Chester
Vice President (2 yrs.)	Robert A. Cummings
Directors (3 yrs.)	N. S. Sprague Hermann Laub

Respectfully submitted,

T. J. Wilkerson,
A. E. Sortore,
L. C. Gerber,
E. E. Lanpher,
C. A. Finley,
K. H. Talbot,
Thos. Fleming, Jr.,
E. D. Harshbarger,
A. D. Neeld,
J. Toner Barr,
C. M. Reppert,
J. D. Stevenson,
J. M. Grant."

These nominations were approved.

The Secretary read the following letter:

"Pittsburgh, Pa., Dec. 4, 1916.

To the President and Board of Direction,

Engineers' Society of Western Penna.

Gentlemen:

In pursuance of authority of Article VII, Section 4, of the By-Laws of the Society, we, the undersigned, request that a special meeting of the Engineers' Society of Western Pennsylvania be called for the purpose of receiving an address to be delivered by D. Robert Yarnall, M. E., Vice President of the Engineers' Club of Philadelphia, on "Engineering Co-Operation and Fellowship."

The date of such special meeting to be as early in the month of December as practicable and which will not conflict with other meetings of the Society; the exact date to be determined later.

N. S. Sprague,
R. A. Cummings,
J. D. Stevenson,
Thos. Fleming, Jr.,
A. E. Sortore,
J. N. Chester,
C. M. Reppert,
Hermann Laub,
T. J. Wilkerson,
E. E. Lanpher."

This request for a special meeting of the Society was referred to the Publication Committee, with the suggestion that the meeting be arranged as promptly as possible.

Mr. George H. Neilson, Chairman of the Entertainment Committee, reported that final arrangements had been completed for the Annual Banquet of the Society, to be held on Monday evening, December 11, in the William Penn Hotel.

Prof. Crabtree, Chairman of the House Committee, reported progress in the matter of looking up quarters for the Society, advising that they now had under consideration quarters in the Magee Building, in Fourth

Avenue; the Berger Building, in Fourth Avenue, and the Hussey Building, in Fifth Avenue.

The meeting adjourned at 5:45 P. M.

ELMER K. HILES, *Secretary.*

A special meeting of the Board of Direction was held in the Society Rooms on Monday, December 18, 1916, at 4:10 P. M., President Samuel E. Duff presiding, Messrs. Raymer, Linton, Mott, Danforth, Stucki, James, Crabtree, Hoerr, Frost and the Secretary being present.

In calling the meeting to order President Duff stated that he had issued the call for a special meeting of the Board of Direction on account of the numerous questions asked him by members of the Society in regard to the double nominations for the Annual Election.

Members had asked about the candidates for the offices of the Society, inquiring as to their record in the Society, etc.

The President stated that he believed all members of the Society were entitled to a complete statement of the facts in answer to the questions raised, and therefore called this meeting of the Board to take such action as was deemed right and proper for the above purpose.

After a general discussion, President Duff introduced a paper which he had had prepared setting forth the personnel of the Nominating Committee, together with the personnel and statistics of the several candidates nominated. The paper also set forth the letter to the Board nominating four other members for office in the Society, together with a statement of personnel and record of work in the Society of these nominees.

The statement was approved and the President authorized to have it printed and mailed to the membership of the Society.

The meeting adjourned at 5:40 P. M.

ELMER K. HILES, *Secretary.*

BOOK REVIEW

BRIDGE ENGINEERING

By J. A. L. Waddell, C.E., B.A.Sc., Ma.E., D.Sc., D.E., LL.D., Consulting Engineer. Two volumes, cloth, 6 x 9 in., 2250 pages, illustrated; John Wiley & Sons, New York. Price $10.00 net.

Reviewed by J. Hammond Smith,
Professor of Civil Engineering, University of Pittsburgh.

This wonderful book of more than 2200 pages, comprising eighty chapters, in two volumes, with 371 illustrations and 186 diagrams, covers bridge building and bridge engineering in all of its phases. It begins with conjectures of the earliest types of bridges and follows down through the epochs of bridge construction to the present time. It discusses in great detail practically all types and classes of bridges known; from the simplest culverts for highways, to the greatest of the cantilever, suspension and arch types.

A good book, on any subject, must have a good author back of it. The eminent engineer proves by this exhaustive treatise that he is also an author of distinction. His clear and convincing style of writing, backed up by his broad and varied experience, makes the reading of this book a pleasure, as well as a source of inspiration and knowledge.

A summary of each of the articles would fill several columns of space. The table of contents covers 28 pages. The index takes 60 pages. All features of engineering which are in any way related to bridge building are carefully discussed and fully explained. Among the main features may be mentioned: Survey of bridge sites, selection of types, loading, estimates and contracts, materials of construction, foundations, falsework, aesthetics and economics of design, designing and detailing, office organization, inspection, erection and maintenance.

The written work is mainly descriptive. Mathematics are used only where necessary to give a complete knowledge of the subject. Tables and diagrams are used extensively. Specifications covering 226 pages, and a glossary of terms covering 222 pages, are valuable features.

5 1916

INDEXED

Tp index in last no of vol

Proceedings of
The Engineers' Society
of
Western Pennsylvania

Vol. 32 February, 1916 No. 1

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Contents

Some Details Often Overlooked by Engineers................ By A. Stucki
The Zinc Smelter of Today.............................By F. E. Pierce
Minutes of Meetings
Alphabetical Advertising Index
Classified Advertising Index

Pittsburgh

Published by the Society, 2511 Oliver Building, Pittsburgh
Monthly except August and September

Fifty cents a number **Five dollars a year**

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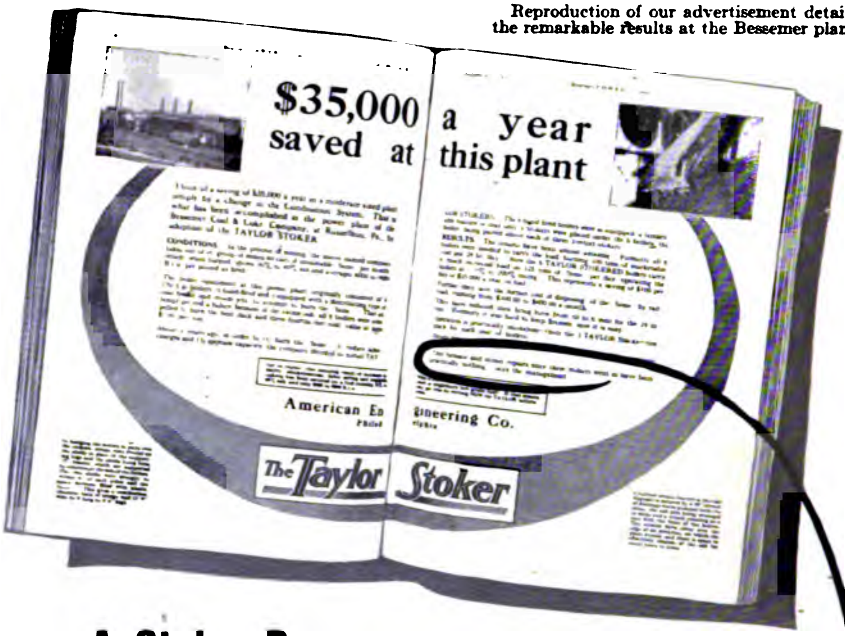
Entered as second class matter at the Pittsburgh Post Office

Reproduction of our advertisement detailing the remarkable results at the Bessemer plant.



$35,000 a year saved at this plant

American Engineering Co.
Philadelphia

The Taylor Stoker

A Stoker-Drama in the Pittsburgh District

The STANDARD STEEL CAR COMPANY of Butler buys its coal from the BESSEMER COAL & COKE COMPANY of Russelton. This relationship has produced unusual consequences.

Last fall that Standard Company chanced to discover that the stokers installed at the Bessemer mine had a maintenance rate surprisingly lower than the stokers equipping their own power plant. This was interesting intelligence, for the Standard people needed new power equipment imperatively, yet their experience with stokers was not encouraging. They had installed three different kinds (two makes of chain grate and one other overfeed type); these stokers, all furious smokers and costly to maintain, still left them short of power.

The Standard Company pressed further its investigation of the stoker over at Russelton. Everything about it pleased them mightily. The result was that the Standard Company recently tore out all the old stokers and put stokers like those at Russelton under their entire boiler battery of 12-264 h.p. units. These stokers not only settle the power question for a long way into the future, but eliminate their smoke and cut maintenance to a fraction of what it was.

> "—they find that the maintenance on TAYLOR Stokers at the Bessemer Coal and Coke Company is far lower than their present equipment"

These stokers are the same make as those installed by the NATIONAL TUBE COMPANY in its Standard, Ellwood City and Kewanee plants; by REPUBLIC RAILWAY & LIGHT COMPANY; by PRESSED STEEL CAR COMPANY; by REPUBLIC IRON & STEEL COMPANY; by U. S. ALUMINUM COMPANY; by W. Va. TRACTION & LIGHT COMPANY—and others in the Pittsburgh District. Why not investigate?

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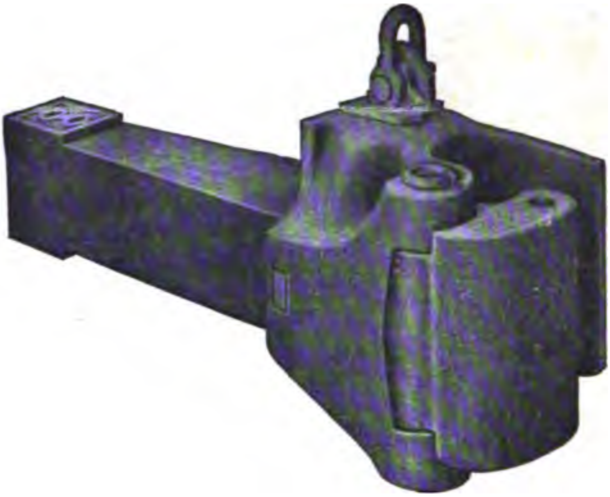
FACTORIES: Pittsburgh, Pa., and Des Moines, Ia.

THE PENN COUPLER



This coupler, which is a combination and modification of the Pitt and Janney X Couplers manufactured by us, has all the desirable features of those couplers, and at the same time retains the simplicity of the early types of the Janney Coupler.

This coupler has the features of a "Lock-Set,'' a "Lock-to-the-Lock" and a "Knuckle-Opener," and complies fully with all the requirements and recommendations of the M. C. B. Association and the Safety Appliance Law.

Lock-Set. Lock setting is accomplished by the locking block when raised to the uncoupling position, resting on a seat on the inside wall of the coupler head, from which seat it is dislodged on the closing movement of the knuckle in the act of coupling.

Lock-to-the-Lock. The locking pin cannot climb, being held in the locked position by the trigger, a projection near the upper end of which engages the under side of the top wall of the coupler head, thus preventing accidental uncoupling.

Knuckle-Opener. The knuckle-opener pushes the knuckle open to its fullest range of movement from a fully closed position or from any partially open position, and its path of movement is such as to insure easy and complete opening of the knuckle.

Especial attention is called to the large area (practically 5 square inches) of the locking surface on the locking block and the knuckle in this coupler, and to the fact that no portion of the locking block extends beyond the bottom wall of the coupler.

This coupler has the desirable feature of easy accessibility of parts, thus facilitating repairs.

Manufactured by

The McCONWAY & TORLEY CO.

PITTSBURGH, PA.

LLEABLE IRON AND STEEL CASTINGS

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V. I

Proceedings of

The Engineers' Society
of
Western Pennsylvania

Vol. 32 March, 1916 No. 2

Contents

Electric Service Problems and Possibilities..............By P. Junkersfeld

The Relation between Engineers and Contractors ....By J. W. Rollins

Minutes of Meetings

Alphabetical Advertising Index

Classified Advertising Index

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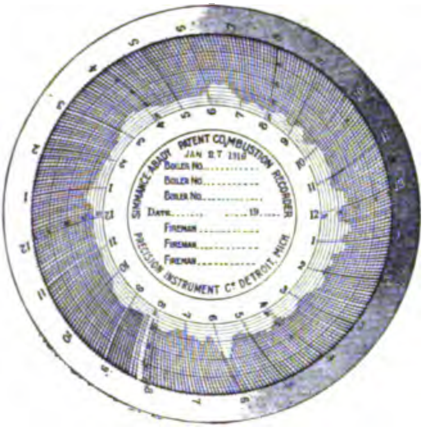

CO_2 charts like this

Plants may secure CO_2 charts like the above occasionally—when an A.1. run of coal happens to coincide with A.1. operating conditions. But to secure such charts consistently—charts running steadily 16%, 17% and 18%—argues intelligent operation working with combustion equipment of the highest type. This plant gets them every day.

The plant is the new Cleveland Municipal lighting station. The maximum load is thus far only 8000 kw.—which means a light load on two of the 5000 kw. machines—yet already a coal rate of 1.8 lbs. per kw. hr. has been reached, and the management expects, with an increased load, to bring this figure close to one pound. And CO_2 Charts like the above may be picked at random from the station files.

The five 1000 h.p. boilers are fired by the TAYLOR stoker. Another reason why you should investigate the TAYLOR.

AMERICAN ENGINEERING COMPANY
PHILADELPHIA
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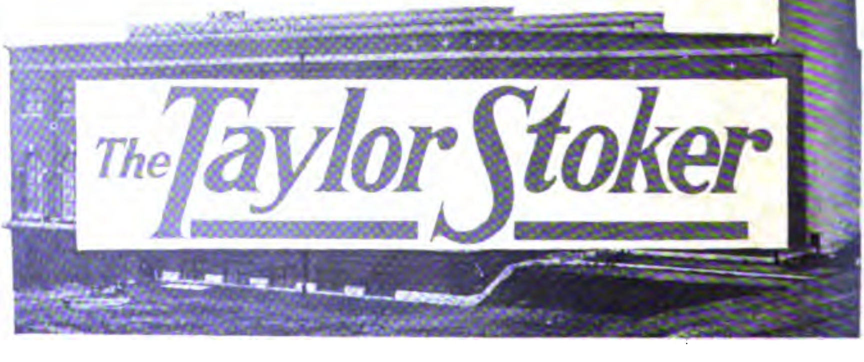

Tech, [illegible]

20 1916

Proceedings of
The Engineers' Society
of
Western Pennsylvania

Vol. 32 April, 1916 No. 3

Contents

Universal Electricity Supply .... By Samuel Insull

After the War .... By Alba B. Johnson

The Necessity for A National Department of Public Works. By Isham Randolph

The extent to which Sewage can be Purified by Practicable Methods of Artificial Treatment now in Use .... By Harrison P. Eddy

Minutes of Meetings

Alphabetical Advertising Index

Classified Advertising Index

Pittsburgh

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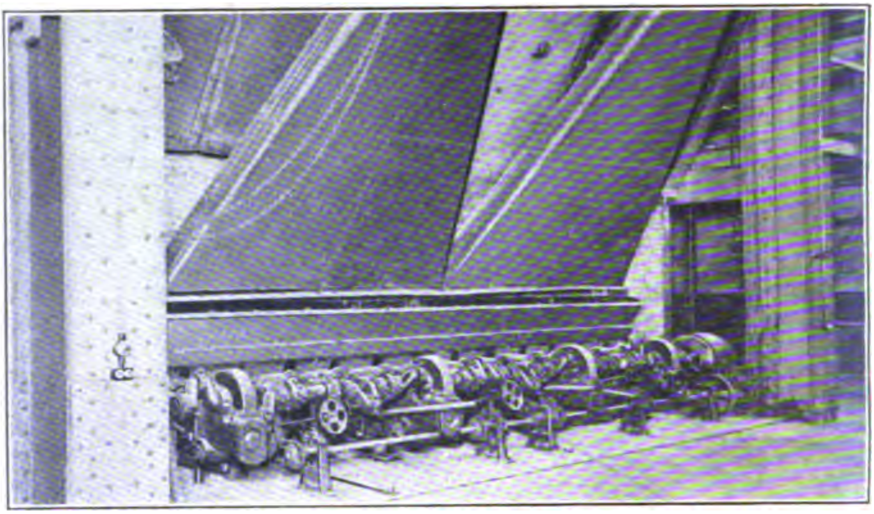

The Plant That Leads The Country

The Detroit Edison Company, recognized as probably the most progressive public service concern in the country, has taken advantage of its long experience to make its new Connors Creek station the latest word in design and practice.

Two 20,000 k.w. machines and four 2365 hp. boilers served by

The Taylor Stoker

are now in operation. The station has been in service a little over a year. Before it had been operating eleven months, a coal rate of 1.43 lbs. per kw. hr. had been reached—apparently the lowest figure yet attained in central station practice in America.

As to the rate at which the boilers are operated, one of the 2365 hp. units has actually carried 16,000 kw.

Detroit is growing like a whirlwind, and a third 20,000 generator with TAYLOR stokered units will soon be added to the above equipment.

Another example of the tendency of the progressive central station to equip with the TAYLOR exclusively.

AMERICAN ENGINEERING CO.

PHILADELPHIA

Pittsburgh Office: Oliver Building.

Tech
32 '16

Proceedings of

The Engineers' Society
of
Western Pennsylvania

Vol. 32 **May, 1916** **No. 4**

Contents

The Mathematical Theory of the Elastic Arch............By Willis Whited
The Utilization of By-Products from the Manufacture of Coke............
By C. G. Atwater

Minutes of Meetings

Book Reviews

Alphabetical Advertising Index

Classified Advertising Index

Pittsburgh

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Be Right the first time-with

The Taylor Stoker

Over half of the TAYLOR stokers sold go to replace older stokers of other types This shows the importance, when it comes to stokers, of being right the first time.

In this connection, it is interesting to note the tendency of large public service concerns especially, when they modernize their equipment or build new stations, to instal the TAYLOR exclusively.

The Northern Ohio Traction & Light Company, New York Edison Company, Philadelphia Electric Company, Detroit Edison Company and Naragansett Electric Company are instances.

The New York Edison Company has steadily replaced older equipment at its two Waterside stations with TAYLOR stokers until both are now exclusively TAYLOR equipped. The new station of this Concern's subsidiary—United Electric Light & Power Company—is completely TAYLO equipped.

Likewise the Detroit Edison has steadily replaced older stokers with TAYLORS at Delray The new station at Connors Creek—the star plan of the country—is completely TAYLOR equipped

The Philadelphia Electric Company, when i built its new station, took advantage of experienc in the old station and placed TAYLOR stoker under all of the twenty 1000 H.P. Boilers.

—and so it goes. It will pay you to investigate this stoker. Why not do so now?

AMERICAN ENGINEERING CO.

PHILADELPHIA

Pittsburgh Office: Oliver Building.

Proceedings of

The Engineers' Society
of
Western Pennsylvania

VDA

Vol. 32 **June, 1916** **No. 5**

Contents

Mobilization of Material and Industrial Resources......By A. L. Humphrey
Scientific Methods in Construction...............By Sanford E. Thompson
Minutes of Meetings
Alphabetical Advertising Index
Classified Advertising Index

Pittsburgh

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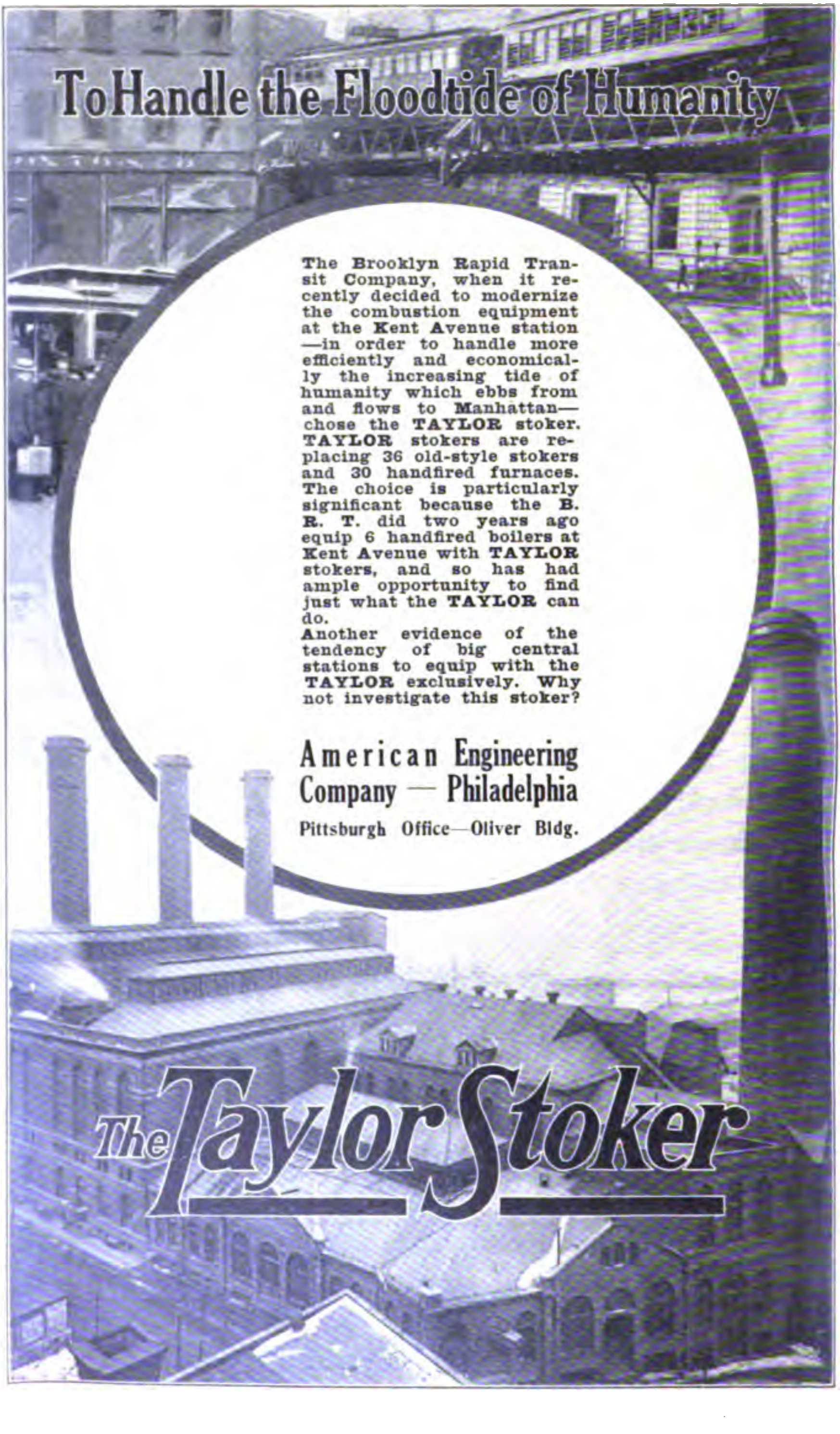

To Handle the Floodtide of Humanity

The Brooklyn Rapid Transit Company, when it recently decided to modernize the combustion equipment at the Kent Avenue station—in order to handle more efficiently and economically the increasing tide of humanity which ebbs from and flows to Manhattan—chose the **TAYLOR** stoker. **TAYLOR** stokers are replacing 36 old-style stokers and 30 handfired furnaces. The choice is particularly significant because the B. R. T. did two years ago equip 6 handfired boilers at Kent Avenue with **TAYLOR** stokers, and so has had ample opportunity to find just what the **TAYLOR** can do.

Another evidence of the tendency of big central stations to equip with the **TAYLOR** exclusively. Why not investigate this stoker?

American Engineering
Company — Philadelphia

Pittsburgh Office—Oliver Bldg.

The Taylor Stoker

INDEXED

Proceedings of
The Engineers' Society
of
Western Pennsylvania

Vol. 32 July, 1916 No. 6

Contents

What can best be done to advance the Interests of the Engineering Profession in the United States.................... By J. A. L. Waddell

Minutes of Meetings

Alphabetical Advertising Index

Classified Advertising Index

Pittsburgh

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Proceedings of

The Engineers' Society
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Western Pennsylvania

Vol. 32 October, 1916 No. 7

Contents

The Glacial Epoch .... By Thomas P. Roberts
Some Aspects of the Testing of Refractories .... By A. V. Bleininger
Minutes of Meetings
Alphabetical Advertising Index
Classified Advertising Index

Pittsburgh

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VI

Proceedings of

The Engineers' Society
of
Western Pennsylvania

Vol. 32 November, 1916 No. 8

Contents

Design of Symmetrical Hingeless Concrete Arches... By Victor H. Cochrane

New Mining Methods as Practiced by The H. C. Frick Coke Company .... By Patrick Mullen

Minutes of Meetings

Alphabetical Advertising Index

Classified Advertising Index

Pittsburgh

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1917

Proceedings of
The Engineers' Society
of
Western Pennsylvania

VDA

Vol. 32 December, 1916 No. 9

Contents

Discussion of New Methods for Mining Bituminous Coal as Practiced by the H. C. Frick Coke Company .... By Patrick Mullen
Factors Affecting Cost of Structural Steel Shop Work..... By E. W. Pittman
Some Items Affecting Cost of Structural Steel Work. By George H. Danforth
Engineering Phases of Smoke Abatement.............. By Osborn Monnett
Minutes of Meetings
Alphabetical Advertising Index
Classified Advertising Index

Pittsburgh

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Proceedings of

The Engineers' Society

of

Western Pennsylvania

Vol. 32 January, 1917 No. 10

Contents

An Outline of the Theory of Heat Transmission and Absorption in Application to Ordinary Engineering Problems..............By John E. Bell

Discussion of The Design of Symmetrical Hingless Concrete Arches.
By Victor H. Cochrane

Minutes of Meetings

Alphabetical Advertising Index

Classified Advertising Index

Pittsburgh

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Proceedings of

The Engineers' Society
of
Western Pennsylvania

Vol. 33 January, 1917 No. 10

INCORPORATED 1880

PAGE

AN OUTLINE OF THE THEORY OF HEAT TRANSMISSION AND ABSORPTION IN APPLICATION TO ORDINARY ENGINEERING PROBLEMS.....797
By JOHN E. BELL

THE DESIGN OF SYMMETRICAL HINGELESS CONCRETE ARCHES........846
By VICTOR H. COCHRANE

APPENDIX

MINUTES OF MEETING..

ALPHABETICAL ADVERTISING INDEX.....................................

CLASSIFIED ADVERTISING INDEX.......................................

ENGINEERS' SOCIETY OF WESTERN PENNSYLVANIA

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ALPHABETICAL ADVERTISING INDEX.

Alpha Portland Cement Co....23
Assoc of Engineering Societies....25
Atlas Portland Cement Co....23

Damascus Bronze Company....3d cover
Diamond National Bank....10
Diescher, S. & Sons....8
Dravo-Doyle Company....17
Duff, Samuel E....8

Elliott, B. K....24
Engineering-Contracting....21

Fohl, W. E....8
Fort Pitt Hotel....10

Gibb Instrument Co....22
Green Engineering Co....26
Gulick-Henderson Co....9

Hagan, Geo. J....8
Homestead Valve Mfg. Co....12
Hunt & Co., Robt. W....9

Iron City Sand Co....21

Jeffrey Mfg. Co....19
Johnston, Jas. H....26
Jones & Laughlin Steel Co....20

Kay, Totten & Powell....8
Kennedy Co., D. J....23
Kennedy, Julian....9
Kier Fire Brick Co....21
Kratzer, W. N. & Co....12

Lufkin Rule Co....24

McClure, Son & Co., G. W....9
McConway & Torley....4th cover
Mackintosh, Hemphill & Co....13
Macfarren, Walter W....8
Mesta Machine Co....13
Metallurgical & Chem. Engrg....25
Morse Twist Drill & Mach. Co....20

National Meter Co....17
Norwich University....25

Phillips Mine & Mill Supply Co....19
Phoenix Roll Works....15
Pittsburgh Construction Co....12
Pittsburgh Des-Moines Steel Co....3d cover
Pittsburgh Meter Co....17
Pittsburgh Piping & Equip. Co....9
Pittsburgh Testing Laboratory....8
Pittsburgh Valve Foundry & Construction Co....9

Rawsthorne Engraving Co., Robt....24
Rodgers Sand Co....21

Scaife & Sons Co., Wm. B....17
Schellenberg, F. Z....8
Seaman, Sleeth Co....15
Smith, L. C. & Bros....22
Somers, Fitler & Todd Co....15
Stahl, K. F....8
Stupakoff Laboratories....9

Taylor-Wilson Mfg. Co....15
Thomas, George P....8

Union Spring & Mfg. Co....15
Universal Portland Cement Co....back cover
University of Pittsburgh....25

Westinghouse Elec. & Mfg. Co....12
Wile Electric Furnace Co....20
Wilkins Co., W. G....8
W t Frederick W....8

For Classified List of Advertisers see pages 14, 16, 18 of Advertising Section.

LIST OF PERIODICALS

ON THE TABLES IN THE READING ROOM OF THE SOCIETY

Academy of Natural Science, Proceedings
American Institute of Electrical Engineers, Proceedings
American Institute of Mining Engineers, Bulletin
American Iron & Steel Institute, Bulletin
American Society of Civil Engineers, Proceedings
American Society of Mechanical Engineers, Proceedings
American Society of Naval Engineers, Journal
American Water Works Association, Bulletin
American Railway Engineering and Maintenance of Way Association, Bulletin
Association of Engineering Societies, Journal of the
Annales de L'Association des Ingenieurs de Grand
Annaes Scientificos de Academia Polytechnia Porto
Anales de la Sociedad Cientifica Argentina

Blast Furnace and Steel Plant, The
Boston Society of Civil Engineers, Journal.

Chamber of Mines, Monthly Journal
Chemical News
Cleveland Engineering Society, Journal
Coal and Coke Operator
Coal Trade Bulletin
Cold Storage and Ice Trade Journal
Colliery Engineer, The
Compressed Air
Concrete
Concrete Institute, Transactions
Contractor, The
Cornell Civil Engineer

Electric Journal
Electric Railway Journal
Electrical Review
Electrical World
Engineering
Engineering Magazine
Engineering & Mining Journal
Engineering News
Engineering Record
Engineering—Contracting
Engineers Club of Dayton, Proceedings
Engineers' Club of Philadelphia, Proceedings
Engineers' Society of Pennsylvania, Journal
Engineering Journal, Canada
Engineering Digest

Fire & Water Engineering
Foundry
Franklin Institute, Journal of the
Fuel Oil Journal

Gas Industry
General Electric Review

Harvard Engineering Journal
Heating & Ventilating Magazine

Ice and Refrigeration
Industrial Engineering

Industrial & Engineering Chemistry, Journal of
Industrial Magazine
Industrial World
Institution of Mechanical Engineers, Journal of the
Institution of Mining Engineers, Transactions of the
Iowa Engineering Society, Proceedings
Iron Age
Iron & Coal Trades Review
Iron Trade Review
Isolated Plant.
Kansas Engineering Society, Proceedings
Les Mois Scientifique et Industrial
Leslie's Weekly
Maschinen Kronstrukteur
Mechanical World
Metal Worker
Metallurgical & Chemical Engineering
Mexican Mining Journal, The
Mines & Minerals
Municipal Engineering
National Engineer
Natural Gas Journal
New England Water Works Association, Journal
Official Gazette U. S. Patent Office (Washington)
Official Journal, Patents (London)
Outlook
Popular Electricity & Modern Mechanics
Popular Science Monthly
Power
Professional Memoirs
Practical Engineer
Railway Age Gazette
Railway Club of Pittsburgh, Proceedings
Railway Engineering
Railway Review
Review of Reviews
Refrigerating World
Revista de Construciones Y Agrimensura
Revista de Obras Publicas E Minas
Revue de L'Igenieur et Index Technique
Royal Society of Arts, Journal

Safety Engineering
Scientific American
School of Mines Quarterly
Scientific American Supplement
Sibley Journal of Engineering
Society of Chemical Industry, Journal of the
St. Louis Railway Club
Steel & Iron

Technical Index
Technical Literature
Technologist
Technology Quarterly
Technology Review
Teknisk Tidskrt
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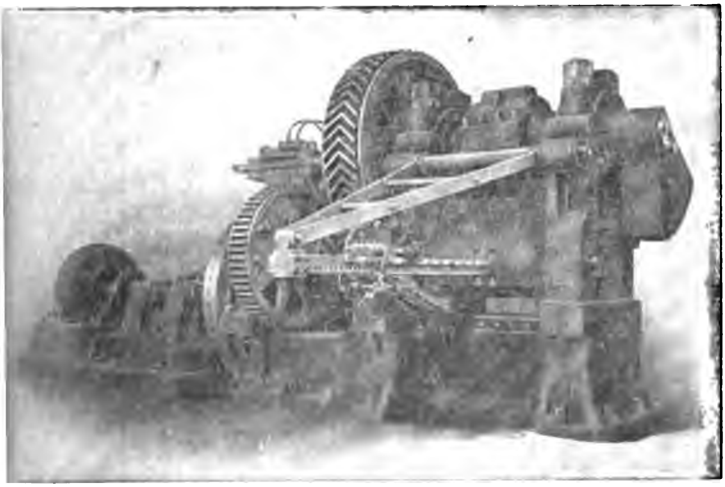

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Mackintosh, Hemphill & Co..............13

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Homestead Valve Mfg. Co................12
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Mesta Machine Co.......................13
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Westinghouse Machine Co................12

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Dravo-Doyle Co.........................17
Pittsburgh Construction Co...............12
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The McConway & Torley Co........4th cove

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The Lufkin Rule Co......................24
Pittsburgh Instrument & Machine Co......24
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Mackintosh, Hemphill & Co...............13
Westinghouse Machine Co................12
Mesta Machine Co.......................13

Engines—Gas.
Mesta Machine Co.......................13
Westinghouse Machine Co................12

Engines—Steam.
Dravo-Doyle Co.........................17
Mackintosh, Hemphill & Co...............13
Mesta Machine Co.......................13
Westinghouse Machine Co................12

Engraving.
Robert Rawsthorne Eng. Co..............24

Feed Water Heaters and Purifiers.
Wm. B. Scaife & Sons Co.................17

Filters, Water.
Wm. B. Scaife & Sons Co.................17

Fire Brick.
Kier Fire Brick Co.......................21

Forging Presses.
Mesta Machine Co.......................13
Southwark Foundry and Machine Co......10

Gas Exhausters.
Southwark Foundry and Machine Co......10

Gas Meters.
Pittsburgh Meter Co.....................17

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Gravel.	
Iron City Sand Co	21
Rodgers Sand Co	21
Grinding Wheels.	
Somers, Fitler & Todd Co	15
Half Tones.	
Robert Rawsthorne Engraving Co	24
Hot Blast Stoves.	
G. W. McClure, Sons & Co	9
Hotels.	
Fort Pitt Hotel	10
Inspectors.	
Gulick-Henderson Co	9
Hunt, R. W. & Co	9
Pittsburgh Testing Laboratory	8
Iron Castings.	
Mackintosh, Hemphill & Co	13
Mesta Machine Co	13
Iron and Steel Works Equipment.	
Mackintosh, Hemphill & Co	13
Locomotives—Electric.	
Jeffrey Mfg. Co	19
Machine Tools.	
Morse Twist Drill & Machine Co	20
Somers, Fitler & Todd Co	15
Taylor-Wilson Mfg. Co	15
Machinery Supplies.	
Somers, Fitler & Todd	15
Machinists.	
Somers, Fitler & Todd Co	15
Machinists Tools.	
Morse Twist Drill & Machine Co	20
Malleable Iron Castings.	
The McConway & Torley Co	4th cove
Meters.	
National Meter Co	17
Pittsburgh Meter Co	17
Mill Builders.	
W. N. Kratzer & Co	12
Pittsburgh Construction Co	12
Mill and Mine Supplies.	
Phillips Mine & Mill Supply Co	19
Pittsburgh Piping & Equipment Co	9
Pittsburgh Valve Foundry & Construction Co	9
Somers, Fitler & Todd Co	15
Mining Machines and Drills.	
Jeffrey Mfg. Co	19
Motors.	
Westinghouse Electric & Mfg. Co	12
Nails.	
Jones & Laughlin Steel Co	20
Oil Filters.	
Elliott Company	11
Piling (steel sheet interlocking)	
Jones & Laughlin Steel Co	20
Pipe Mill Machinery.	
Taylor-Wilson Mfg. Co	15
Piping.	
Pittsburgh Piping & Equipment Co	9
Pittsburgh Valve, Foundry & Construction Co	9
Plaster.	
D. J. Kennedy Co	23
Power—Electric.	
Duquesne Light Co	10
Power—Electric.	
Duquesne Light Co	10
Power Plants.	
Westinghouse Electric & Mfg. Co	12
Westinghouse Machine Co	12
Power Plant Specialties.	
Dravo-Doyle Co	17
Elliott Company	11
Green Engineering Co	26
Homestead Valve Mfg. Co	12
Jas. H. Johnston	26
Pittsburgh Meter Co	17
Pittsburgh Piping & Equipment Co	9
Pittsburgh Valve, Foundry & Construction Co	9
Steam Equipment Mfg. Co	26
Presses, Punches.	
Mackintosh, Hemphill & Co	13
Printing.	
Robert Rawsthorne Engraving Co	24
Publications.	
Engineering and Contracting	21
Metallurgical & Chemical Engineering	25
Pulleys.	
Jones & Laughlin Steel Co	20
Pyrometers.	
Gibb Instrument Co	22
S. H. Stupakoff	9
Rods.	
Jones & Laughlin Steel Co	20
Rolling Mills.	
Mackintosh, Hemphill & Co	13
Mesta Machine Co	13
Rolls.	
Phoenix Roll Works—Seaman, Sleeth Co	15
Mesta Machine Co	13
Rules and Tapes.	
B. K. Elliott Co	24
Lufkin Rule Co	24
Sand.	
Iron City Sand Co	21
Rodgers Sand Co	21
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Phillips Mine & Mill Supply Co	19
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Classification	Advertiser	Page
Shears.	Mackintosh, Hemphill & Co	13
Spikes.	Jones & Laughlin Steel Co.	20
Springs.	Union Spring & Mfg. Co	15
Stacks.	Wm. B. Scaife & Sons Co	17
Stand Pipes.	Pittsburgh-Des Moines Steel Co	3d cover
Steam Goods.	Elliott Company	11
	Homestead Valve Mfg. Co	12
	Jas. H. Johnston	26
	Steam Equipment Mfg. Co	26
Steam Turbines.	Southwark Foundry and Machine Co	10
	Westinghouse Machine Co	12
Steel (structural).	Jones & Laughlin Steel Co	20
Steel Castings.	The McConway & Torley Co	4th cover
	Mackintosh, Hemphill & Co.	13
	Mesta Machine Co	13
	Union Spring & Mfg. Co	15
Stokers—Mechanical.	American Engineering Co	2d cover
	Green Engineering Co	26
	George J. Hagan	8
	Westinghouse Machine Co	12
Structural Steel.	Jones & Laughlin Steel Co	20
	Pittsburgh Construction Co	12
Surveying Instruments.	B. K. Elliott Co	24
	Lufkin Rule Co	24
	Pittsburgh Inst. & Mach. Co	24
Tanks.	Pittsburgh-Des Moines Steel Co	3d cover
	Wm. B. Scaife & Sons Co	17
Tapes.	The Lufkin Rule Co	24
Tin Plate.	Jones & Laughlin Steel Co.	20
Transmission Equipment.	Jones & Laughlin Steel Co.	20
Tube Mill Equipment.	Taylor-Wilson Mfg. Co	15
Turbines—Steam.	Dravo-Doyle Company	17
	Westinghouse Machine Co.	12
Typewriters.	L. C. Smith & Bros	2
Valves.	Homestead Valve Mfg. Co	12
	Jas. H. Johnston	26
	Pittsburgh Piping & Equipment Co.	9
	Pittsburgh Valve, Foundry & Construction Co	9
	Steam Equipment Mfg. Co	26
Water Filters.	Elliott Company	11
	Wm. B. Scaife & Sons Co	17
Water Meters.	National Meter Co	17
	Pittsburgh Meter Co	17
Water Softening and Purifying Systems.	Wm B. Scaife & Sons Co.	17
Water Strainers.	Elliott Company	11
Water Towers.	Pittsburgh-Des Moines Steel Co	3d cover
Wood Preserving.	Pittsburgh Wood Preserving Co.	1
Wire—Copper, Electric.	Jones & Laughlin Steel Co.	2
	Westinghouse Electric & Mfg. Co	12

CLASSIFIED PROFESSIONAL CARDS.

Classification	Name	Page
Attorneys—Patent.	Kay, Totten & Powell	8
	Keller, M. Arthur	8
	Winter, Frederick W	8
Chemists.	Stahl, K. F	8
Engineers—Civil.	Diescher, S. & Sons	8
	Donley, Wm. Mc	8
	Duff, Samuel E	8
	Hunt, Robert W. & Co	9
	Schellenberg, F. Z	8
	Swensson, Emil	9
	Wilkins Co., W. G	8
Engineers—Chemical.	Hunt, Robert W. & Co	9
	Pittsburgh Testing Laboratory	8
Engineers—Mechanical.	Diescher, S. & Sons	8
	Hagan, George J	8
	Kennedy, Julian	9
	Macfarren, Walter W	8
	McClure, Son & Co.	9
	Stupakoff, S. H	9
	Thomas, Geo. P	8
Engineers—Mining.	Clapp, Frederick G	8
	Fohl, W. E	8
	Schellenberg, F. Z	8
Geologists.	Clapp, F. G	8
Inspectors.	Gulick-Henderson Co	9
	Hunt, R. W. & Co	9
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Power Plant Engineers.	Dravo-Doyle Co.	17

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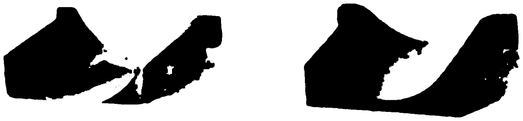

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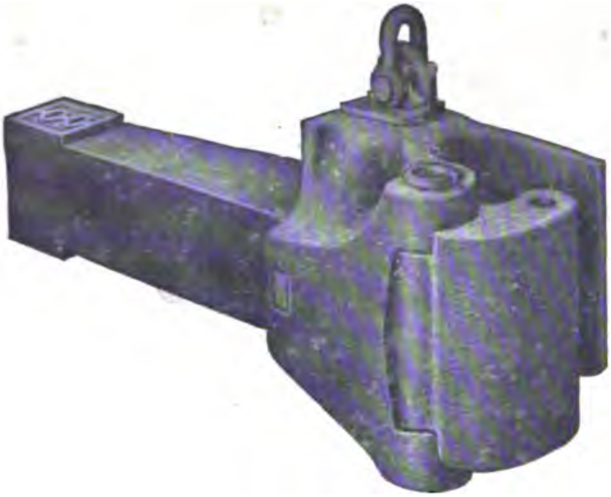

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